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CSSANE

A CODE FOR SYSTEM SURVIVABILITY

ANALYSIS - NUCLEAR EFFECTS

THESIS

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A computer code has been written to determine aerospace system survivability to selected nuclear effects. A special case of survivability is treated in which system survival is based on a comparison of the sure-kill vulnerability level and the computed free field nuclear effects levels. The code consists of two functional parts. One part is the guiding program which conducts the survivability study; the other part consists of individual subroutines which evaluate free field nuclear environment levels. Subroutines have been included to evaluate the blast and thermal environments. At a later date, subroutines will be added to evaluate the effects levels for x-ray, gamma ray, neutrons, and EMP. The present code is capable of handling from one to ten nuclear bursts and up to 100 similar vehicles in a single program run. Any type of system may be treated for which the effects vulnerability levels are known. The code has been written in the FORTRAN EXTENDED language for a CDC 6600 computer with a scope 3.3 compiler. Central core memory required is approximately 40,000 octal words and run times are on the order of seconds. A sample problem has been included to illustrate the type of study that may be performed and to demonstrate the use of the program.

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CSSANE

A CODE FOR SYSTEM SURVIVABILITY ANALYSIS - NUCLEAR EFFECTS

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
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in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by

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June 1972

Preface

The computer code presented in this report is called a code for system survivability analysis. It is designed to serve as a tool for engineering studies of system survival rather than operations analysis, though the latter interest may be served as well.

The following analogy is given to define and clarify the term "survivability code" as used in this report. As the human body is vulnerable in varying degrees to many diseases, so is the aerospace system vulnerable in varying degrees to each of the nuclear effects. The survival of the body is dependent partially on the intensity of exposure to disease. Exposure levels are often related to the environment. Similarly, survival of systems to the threat of nuclear effects depends on the system vulnerability and on the threat level. This code evaluates a rather special case of survivability in which the survival determination is based on a sure-kill vulnerability level and the computed threat level.

I hope that this program will help to emphasize the individuality of each of the nuclear effects and the variation in the relative importance of each, depending on the burst and receiver positions.

I wish to thank Captain George Kuch and Mr. Alfred Sharp of the Air Force Weapons Laboratory at Kirtland AFB for their assistance in providing information on the thermal and blast

effects. The guidance and suggestions of my thesis advisor, Dr. Charles J. Bridgman, are also gratefully acknowledged.

Robert G. DeRaad

Contents

List of Figures

List of Tables

Abstract

A computer code has been written to determine aerospace system survivability to selected nuclear effects. A special case of survivability is treated in which system survival is based on a comparison of the sure-kill vulnerability level and the computed free field nuclear effects levels. The code consists of two functional parts. One part is the guiding program which conducts the survivability study; the other part consists of individual subroutines which evaluate free field nuclear environment levels. Subroutines have been included to evaluate the blast and thermal environments. At a later date, subroutines will be added to evaluate the effects levels for x-ray, gamma ray, neutrons, and EMP. The present code is capable of handling from one to ten nuclear bursts and up to 100 similar vehicles in a single program run. Any type of system may be treated for which the effects vulnerability levels are known. The code has been written in the FORTRAN EXTENDED language for a CDC 6600 computer with a scope 3.3 compiler. Central core memory required is approximately 40,000 octal words and run times are on the order of seconds. A sample problem has been included to illustrate the type of study that may be performed and to demonstrate the use of the program.

CSSANE

A CODE FOR SYSTEM SURVIVABILITY ANALYSIS - NUCLEAR EFFECTS

I. Introduction

The effects of a nuclear environment on aerospace systems is an important factor in systems analysis. The system, the threat, and the flight regime all enter into the analysis. Nuclear weapons are of special interest because of the variety of effects that pose a threat. Additionally, the relative importance of each threat varies with the burst altitude and the flight regime.

The objective of this study was to develop a computer code to evaluate the survivability of systems in a nuclear environment. There are existing codes that include survivability analysis as part of an operations analysis investigation and there are codes that evaluate the free field nuclear effects levels without regard to system survivability. This code conducts a "special case" survivability analysis for systems which are undergoing a specified nuclear attack. The code evaluates levels of selected nuclear effects and evaluates system survival based on a comparison of those levels to sure-kill vulnerability levels which are specified by the user. Information furnished by the code includes the relative level of the various effects in addition to survivability.

The computer program consists of a routine named GUIDE which accepts data input and conducts the study, and a set of subroutines that computes effects levels and evaluates the survival of systems. Initially, subroutines have been included to evaluate both blast and thermal environments. This type of organization was chosen so that the program could be easily expanded to include subroutines for x-ray, gamma ray, neutrons, and EMP.

Chapter II of this report describes the computer program in detail. The description includes capabilities, limitations, and options available to the user. Chapter III describes the treatment of blast effects, the subroutine for blast computations, and the capabilities of the subroutine. Similar information concerning thermal effects is presented in Chapter IV. Chapter V presents the results and conclusions including recommendations. A statistical model for obtaining a normally distributed variable for targeting purposes is presented in Appendix A. Appendix B includes a list of major program variables along with definitions and the location where each variable appears first in the code. Appendix C contains detailed instructions for making the required data input. Appendix D is a source listing of the complete code and Appendix E presents the input and output of a sample problem.

II. The Survivability Analysis Code

A study of system survivability to nuclear effects is a function of the system, the threat, and the flight regime. A survivability analysis requires a knowledge of the vulnerability of a system and of the threat level. Vulnerability has been defined as the level of a specified effect that will cause a finite degradation in the capability of a system to perform its mission. Survivability is defined as the capability of a system to accomplish a specified mission while withstanding the effects of a nuclear environment. For the purposes of this study, system survivability is based on a comparison of the computed threat levels to specified "sure-kill" vulnerability levels.

A description of the code that was developed to perform the survivability study is presented in this chapter. In addition to the description, the capabilities, limitations, options, data input, and the output of the code are discussed.

Description of the Computer Program

The code is named CSSANE, "A Code for System Survivability Analysis - Nuclear Effects". It has been developed to provide a simple and easy-to-use method for determining survivability of systems in a well defined nuclear threat situation. This determination is based on sure-kill vulnerability levels which are specified by the user for each nuclear effect threat under consideration. The free field nuclear effect environments are calculated in subroutines and

comparisons are then made to the specified vulnerability levels. This comparison results in a kill, no-kill decision. This type of an analysis does not lend itself to operations analysis but is rather intended as an aid in engineering studies of system survivability.

The code consists of two functional parts. The main program, GUIDE, controls or directs the survivability study and is one part. The second part of the program consists of a set of individual subroutines which evaluate each nuclear threat level.

Data required by the code are entered in program GUIDE. This includes the yield and the time of burst for one or more nuclear detonations; the position in space and the velocity vectors for one or more similar vehicles; and the vulnerability levels of those vehicles to each of the nuclear effects which are to be studied.

The burst locations, the incremental time to each succeeding burst, the time-updated vehicle positions and velocities, the vulnerabilities, and the slant ranges from burst to vehicle position are maintained in GUIDE. In addition, the subroutines which evaluate the effects levels are called from GUIDE.

Perhaps the best way to demonstrate the intended use of the program and its capabilities is to illustrate a typical aerospace system - nuclear weapon encounter. A sketch which describes the physical situation and most of the input parameters that are required is included as Fig. 1.

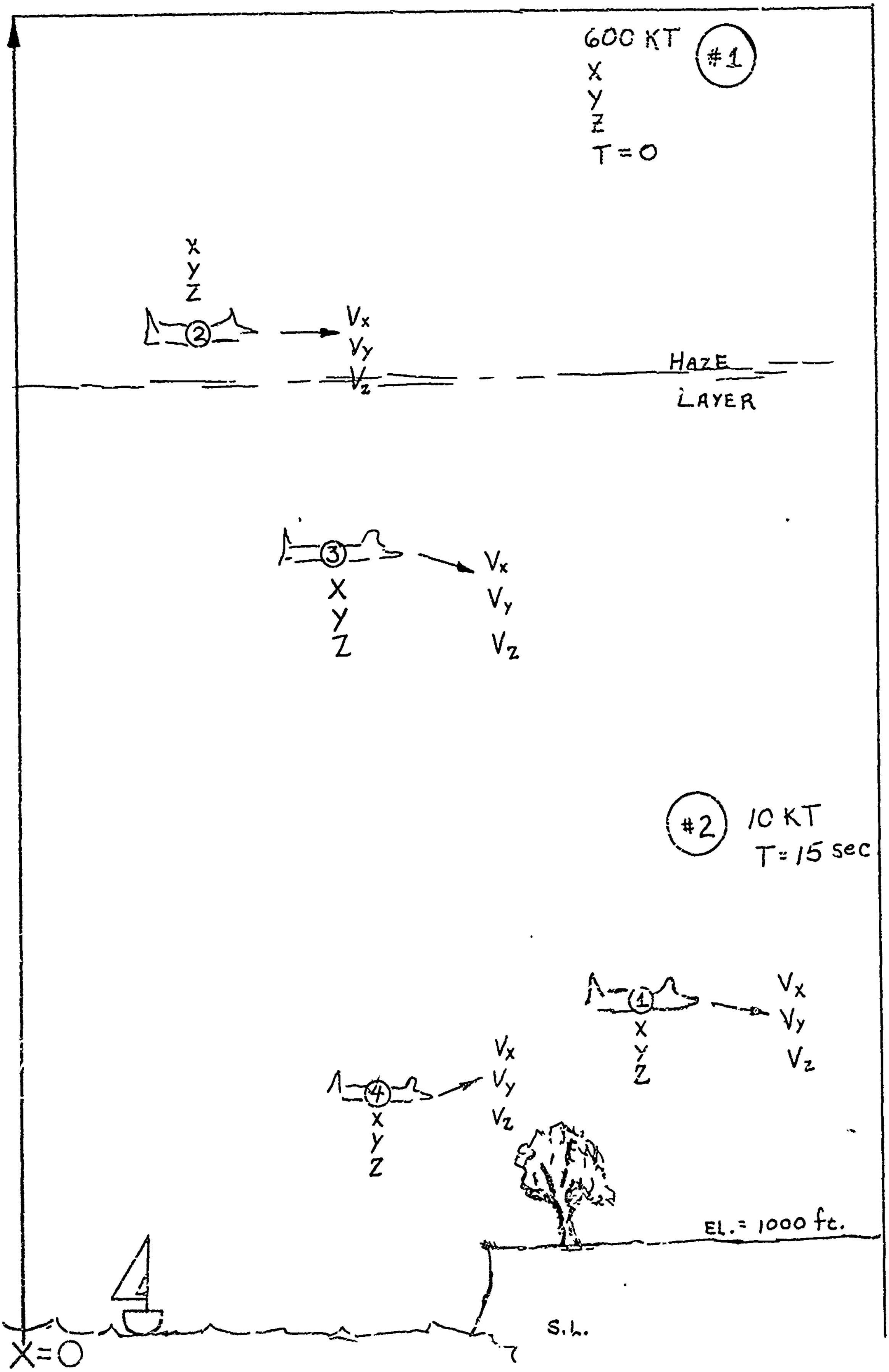

Fig. 1. System-Nuclear Weapon Encounter.

Figure 1 describes a situation in which four similar vehicles with common vulnerability numbers are subjected to two separate nuclear bursts. Each of the vehicles has been assigned initial x, y, z coordinates in an arbitrary, sea level reference and velocity components at time T = 0. The ground level and the maximum altitude of a uniform haze layer over the earth must be specified. Both of these values may be zero. A visibility factor in miles must be specified for the haze cover.

The nuclear threat is provided by two bursts, the first of which is intended to simulate an indirect attack; the second, to simulate a direct attack on vehicle number one. The indirect attack consists of a large yield weapon which is detonated at time T = 0 and at position x, y, z as specified by the user. The direct attack (burst number two) is specified by yield and time. Its position is automatically determined, based on the target point which is the updated vehicle position, and a spherical probable error which must be specified for a given weapon delivery system.

The program is cycled through its evaluation procedures for each burst. In this cycle, the vehicle positions are updated to the time of each burst, the nuclear effects levels of interest are computed for each vehicle, and the survival determination is made on each vehicle. A record is kept of the surviving vehicles and printouts are made for each burst, noting the vehicles which have been destroyed, the nuclear effect responsible, and the levels of threats encountered by

each vehicle. Once a vehicle has been designated as destroyed, it is removed from the program and no further calculations are performed on it.

Program Options

There are five options in this code and they are specified by data input to GUIDE. The most important option determines which effects are to be considered in the survivability analysis. The option for evaluation of any effect is chosen by entering a positive value for the vulnerability level of that effect. The other four options allow a choice of a nonstandard atmosphere, a choice of method of burst placement, a choice of the type of output, and a choice of employing reactive turning (dodging the burst). The method for choosing these options is described in Appendix C, "Details of Data Entry".

The ARDC standard atmosphere may be modified by specifying the temperatures at sea level, burst height, receiver height, and the terrain level. Burst placement may be specified by the user through data input, or may be obtained from subroutine TARGET. Output may consist of a listing of all values of each effect parameter at each vehicle plus the survivability result, or it may be reduced to just the survivability result.

Capabilities

The code is capable of handling from one to ten nuclear bursts if they are placed automatically by subroutine TARGET.

Any number of bursts may be entered if the burst positions are specified by the user. There is no restriction on mixing the mode of burst placement except that the number of bursts placed automatically cannot exceed ten for any given program run. Each burst may vary in yield and may be entered with any time increment desired. The bursts are entered in time sequence and each burst is treated separately even if two bursts are entered at coincident times.

Any number from 1 to 100 vehicles can be entered for a single program run. They may be traveling in different directions, at different altitudes, and at different speeds. As a result, it is possible to evaluate systems that are operating in unrelated flight regimes without rerunning the program. Any type of system, whether in the air or stationary on the ground, may be treated provided its vulnerability is known.

There is a capability to simulate the direct attack by calling subroutine TARGET which places the burst in a normal distribution about the target point. This type of placement allows for a margin of error inherent in the guidance system of the weapon delivery vehicle. That error is generally described as the spherical probable error, spe. The spe is the radius of a sphere about the target point which should contain approximately 50% of the burst positions. The target point is always chosen as the first filled slot in the vehicle array.

A statistical approximation often used in weapon simulation work is used to obtain the normally distributed x, y, z set of coordinate points. These coordinates then represent the burst position. A development of the approximation is given in Appendix A.

If the burst position is entered as input, it is possible to change the velocity vectors of one or all of the vehicles at the time of burst detonation. A change of the velocity vectors away from the burst point can roughly simulate reactive turning. Also, for each burst, to eliminate unnecessary calculations each vehicle is tested for intercept with the fireball and for intercept with the ground. Vehicles found in these situations are annotated as destroyed and are removed from the program.

Subroutines have been included to evaluate survival to blast and thermal effects. Subroutine BLAST1 makes survival tests based on dynamic pressure and overpressure levels; subroutine THERM investigates survival to thermal fluence levels.

Limitations

There are some limitations that exist because of input data that cannot be changed once it is entered. The vulnerabilities are not variable within a run, and only those effects are evaluated for which a vulnerability level is specified. Consequently, it is not possible to vary the effects which will be evaluated during a given run. A single

vulnerability for each effect also means that only one type of vehicle can be treated per run. In addition, it is not easy to alter the flight regime of a vehicle since its heading, speed, and position are non-variable input. (The reactive turning capability excepted.)

The flight regime may restrict the use of certain effects subroutines, primarily because of maximum altitude limitations on some of the calculations. The capabilities and restrictions of the effects subroutines are given in Chapters III and IV. Also, the order in which the different effects are evaluated is determined by the program, not by the input.

Data

Data Input. All input values that are required are entered into the program GUIDE. There are a total of ten input statements. The first six are executed once for each run. The last four are executed once for each burst in a run.

The following is a word description of the content of each of the first six input statements:

1. This "read" enters the visibility, the water vapor pressure, the albedo (ground surface reflectance), and altitude of the haze layer (one input card required).
2. Enters the number of vehicles and the number of bursts to be studied (one input card required).

3. Enters the values associated with choice of a non-standard atmosphere (one input card required).
4. Sequentially enters the values for coordinate positions and velocities of each vehicle (one input card required for each vehicle originally entered).
5. Enters the list of integers that are used to pre-cycle the random number generator required for targeting (one card required).
6. Enters the vulnerability levels for survivability determinations (one card required).

Data that must be entered repeatedly for each burst is described below:

1. This input statement enters the incremental time of burst, weapon yield, burst height above ground, and integers for the options of burst placement, data output, and change of velocity vectors (one card required).
2. Enters the coordinate points of burst (one card required).
3. Enters new values of velocity vectors (one card required for each vehicle originally entered).
4. Enters the value of spherical probable error (one card required).

Note: Specific instructions for data entry are given in Appendix C.

Data Output. Hollerith statements are used to supplement and clarify the output data. The data that is input is

listed and identified again in the output. The vehicle positions and velocities at the time of each burst are listed. In addition, for each burst, the method of placement and the burst position are given.

Results of the survivability tests are printed separately for each burst. For those vehicles that are destroyed, the effect, the level of the effect, and the vulnerability level are all given in a removal statement. Removal statements are also printed for the fireball and the ground intercept cases.

Summary

The computer code consists of two parts. The program GUIDE accepts data and directs the survivability study; the subroutines compute effects levels and make survival analyses. This organization was chosen so that additional subroutines for other effects could be added with a minimum of change.

Subroutines for evaluation of blast and thermal effects are included. Survivability to dynamic pressure and to overpressure levels is tested by subroutine BLAST1; survivability to thermal fluence levels is tested in subroutine THERM. The program allows a choice of the effects to be evaluated, method of burst placement, and type of data output. There is also a capability to specify a nonstandard atmosphere and to simulate reactive turning.

A full description of the data and the format for its entry are given in Appendix C. Capabilities and restrictions

for each of the effects subroutines are given in the chapters written for each subroutine. The subroutine and the methods for calculation of blast effects are presented in Chapter III. Chapter IV contains similar information for thermal effects.

III. Computation of Blast Environments

Blast Phenomenon

Blast phenomenon can be computed using analytic or empirical methods. There are analytic hydrodynamic codes that yield extremely accurate shock parameter values, but at the expense of lengthy computer runs. Empirical methods, on the other hand, scale the data of a standard explosion to obtain shock values for other specified bursts. One such method for predicting shock phenomenon is the Sachs scaling technique. The blast effects information presented here is based on Sachs scaling and was taken directly from AFWL-TR-70-85 (Ref 7). The report includes a code named SABER which evaluates blast parameters. The BLAST1 subroutine of CSSANE borrows the methods of SABER to find blast effects levels for given receiver positions and slant ranges. A capability for receiver motion was added to allow application to aircraft in flight. The calculations of shock parameters include methods to account for an inhomogeneous atmosphere, reflection from the earth (fused shock region), and a blast efficiency factor.

Sachs Scaling

The Sachs equations for scaling have been developed in Ref 7, pp. 2-12. A summary of these equations is given below.

Overpressure (ΔP) psi

$$(\Delta P)_T = (\Delta P)_m \left(\frac{P_{aT}}{P_{am}} \right) \qquad (1)$$

Range (R) ft

$$R_T = R_m \left(\frac{E_T}{E_m} \right)^{1/3} \left(\frac{P_{am}}{P_{aT}} \right)^{1/3} \tag{2}$$

Time of Shock Arrival (t_a) sec

$$t_{aT} = t_{am} \left(\frac{E_T}{E_m} \right)^{1/3} \left(\frac{P_{am}}{P_{aT}} \right)^{1/3} \left(\frac{T_{am}}{T_{aT}} \right)^{1/2} \tag{3}$$

Time of Positive Phase Duration (t_{pp}) sec

$$t_{ppT} = t_{ppm} \left(\frac{E_T}{E_m} \right)^{1/3} \left(\frac{P_{am}}{P_{aT}} \right)^{1/3} \left(\frac{T_{am}}{T_{aT}} \right)^{1/2} \tag{4}$$

Gust Velocity (U) ft/sec

$$U_T = U_m \left(\frac{C_{aT}}{C_{am}} \right) \tag{5}$$

Density, Shocked Air (ρ_s) slugs/ft^3

$$\rho_{sT} = \rho_{sm} \left(\frac{\rho_{am}}{\rho_{aT}} \right) \tag{6}$$

where the subscript T applies to the explosion under investigation; the subscript m applies to the 1 KT model, and

P_a = ambient pressure (psi)

E = energy of explosion (KT)

T_a = ambient temperature (°R)

C_a = ambient speed of sound (ft/sec)

ρ_a = ambient density (slugs/ft^3)

Effects of a Nonhomogeneous Atmosphere

The Sachs scaling equations are satisfactory for the coaltitude burst and receiver. However, the nonhomogeneous atmosphere prevents a direct application in the noncoaltitude case. That case may be handled by applying the Ledsham-Pike alpha correction (Ref 7, 12-14) to overpressure calculations and a modified Sachs scaling to the other shock parameters.

The alpha correction method was used to find overpressure values because of its accuracy and because the overpressure is a value that is subsequently used to compute other shock parameters. The remaining parameters are found by the modified Sachs scaling method which assumes the blast wave is propagating from the burst to the receiver under ambient conditions of the altitude of the receiver. Test explosions have verified a correlation of measured effects values to those obtained by use of the alpha and modified scaling methods.

In the alpha correction method, the overpressure at the receiver is obtained by multiplying the overpressure at the burst altitude by the alpha correction factor.

$$\Delta P_R = \Delta P_B \left(\frac{P_R}{P_B} \right)^{\alpha} \qquad (7)$$

This factor is the ratio of the pressure at the receiver altitude to pressure at the burst altitude raised to the power alpha. The exponent, alpha, is derived from empirical data and theoretical calculations and is a function of the

scaled range, burst to receiver (see Fig. 2).

The modified scaling equations for the noncoaltitude case are presented here in Eqs (8) through (14) (Ref 7, 22-26).

Time of Shock Arrival (t_{aT}) sec

$$t_{aT} = \frac{t_{am}}{\bar{C}_z(\bar{P}_z/E_T)^{1/3}} \tag{8}$$

where

t_{am} = time of shock arrival for model (sec)

E_T = energy yield of burst (KT)

$$\bar{P}_z = \frac{P_z}{P_{SL}} \tag{9}$$

$$\bar{C}_z = \frac{C_z}{C_{SL}} \tag{10}$$

P_z = ambient pressure at receiver (psi)

P_{SL} = ambient pressure at sea level (psi)

C_z = ambient speed of sound at receiver (ft/sec)

C_{SL} = ambient speed of sound at sea level (ft/sec)

Note: If the receiver is in the fused shock region (Mach stem) the energy term E_T must include the amplification factor F_r (see section on reflected shock reinforcement p. 19).

The Rankine-Hugoniot relations between density - particle velocity, particle velocity - speed of sound, and dynamic

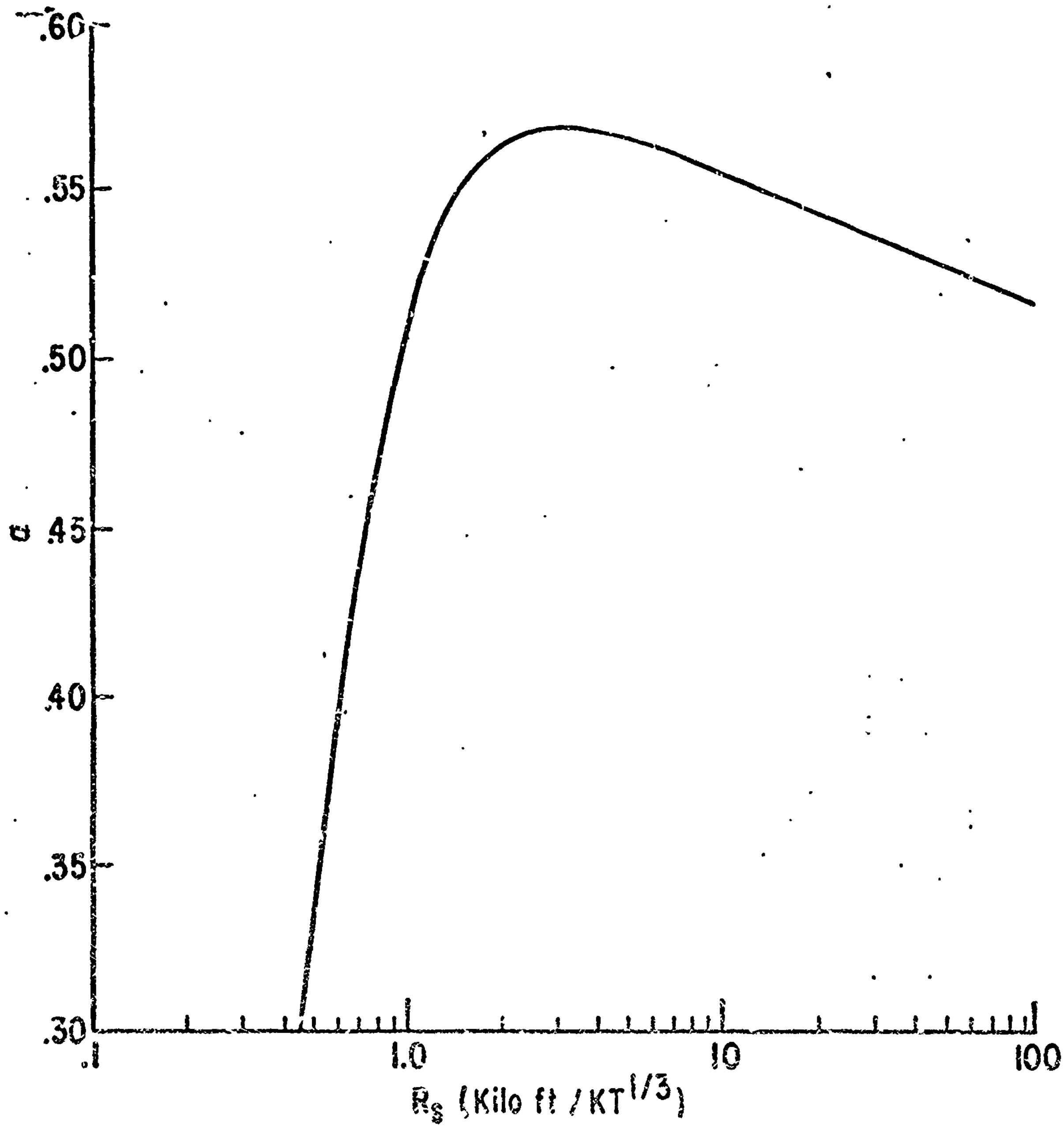

Fig. 2. Ledsham-Pike Alpha Correction as a Function of Scaled Range (Ref 7, 14).

pressure - particle velocity along with modified scaling give the following (Ref 7, 24-26):

Shock Front Velocity (C_s) ft/sec

$$C_s = C_z \left(1 + \frac{6\Delta P_z}{7P_z} \right)^{1/2} \quad (11)$$

where ΔP_z = peak overpressure at receiver

Density Behind the Shock (ρ_s) slugs/ft^3

$$\rho_s = \rho_z \left(\frac{7 + 6\Delta P_z/P_z}{7 + \Delta P_z/P_z} \right) \quad (12)$$

where ρ_z = ambient atmospheric density at receiver

Peak Particle Velocity (U_p) ft/sec

$$U_p = \frac{5}{7} C_z \left(\frac{\Delta P_z}{P_z} \right) \left(\frac{6\Delta P_z}{7P_z} + 1 \right)^{-1/2} \quad (13)$$

Dynamic Pressure (q) psi

$$q = \frac{5}{2} \left(\frac{\Delta P_z^{\,2}}{7P_z + \Delta P_z} \right) \quad (14)$$

Region of Reflected Shock Reinforcement

Shock phenomenon for bursts near the ground is complicated by the reflection of the shock front off the ground into the region of previously shocked air. The reflected shock, traveling more rapidly in the heated air, overtakes

the basic shock front and fuses with it to form a reinforced shock region called the Mach stem. The triple-point path, originating at a point on the earth some radial distance from ground zero, describes a boundary below which there exists a region of shock reinforcement.

A yield amplification factor, F_r, has been determined from experimentation for both the region near the triple-point path and for the region considered far within the Mach stem. For points near the path, the yield multiplying factor, F_r, is given in Fig. 3 as a function of scaled altitude of burst $(Kft/(KT)^{1/3})$. The multiplying factor for far geometries, i.e., points which are at scaled ranges greater than 100 $ft/(KT)^{1/3}$ from the triple point path, is given by

$$F_r = 2.33 - 0.025\ R_s \tag{15}$$

a function of the scaled range (R_s) in $Kft/(KT)^{1/3}$ (Ref 7, 64).

Positive Phase Durations

The times of positive phase duration for overpressure, material velocity, and overdensity have also been developed from scaling methods (Ref 7, 26-31). Empirical relations have been derived for the positive duration of overpressure $[(\Delta P)_t]_m$, the ratio of scaled positive duration of material velocity to scaled duration of overpressure $[G_t/(\Delta P)_t]_m$, and the ratio of scaled positive duration of overdensity to scaled duration of overpressure $[(\Delta\rho)_t/(\Delta P)_t]_m$. These empirical relations in conjunction with the general equation for positive phase durations, Eq (4), yield the following:

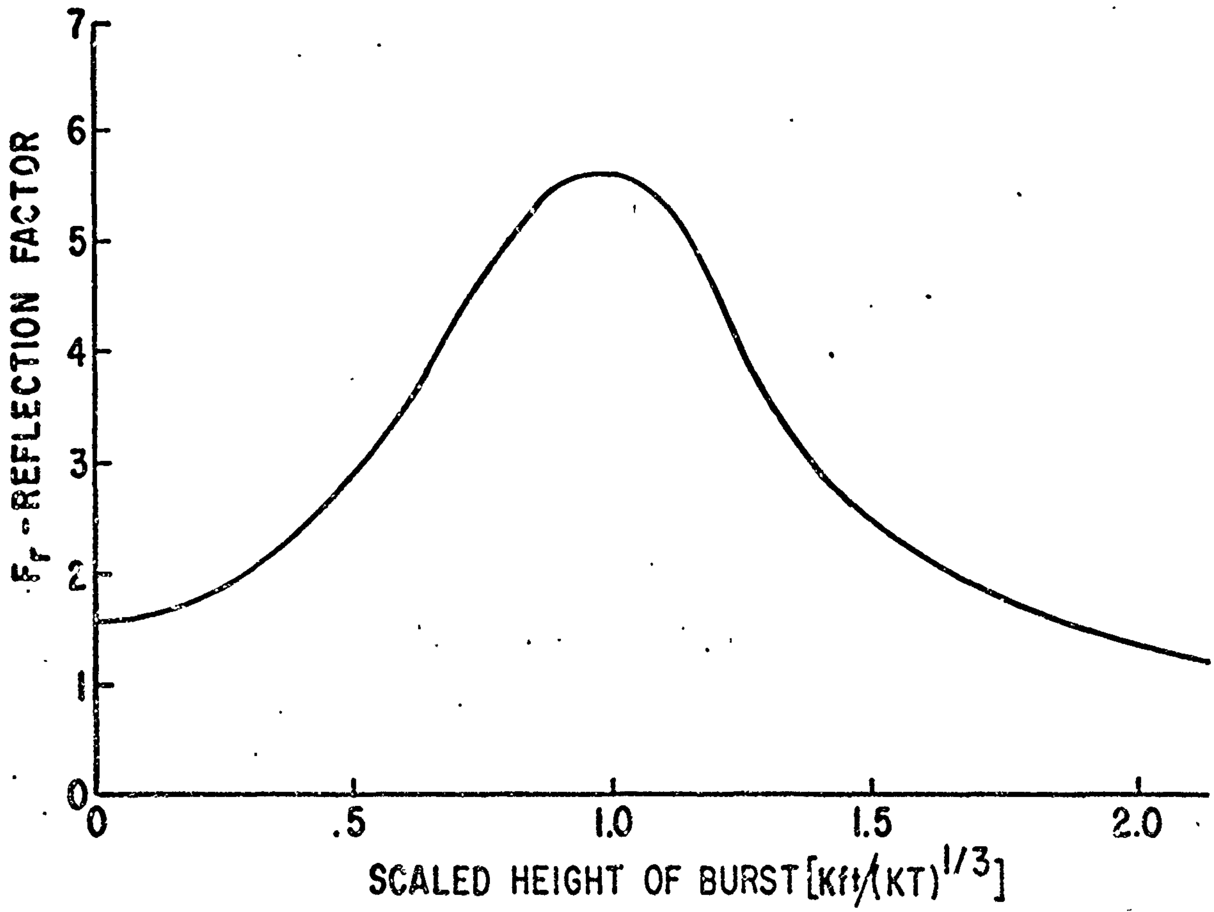

Fig. 3. Yield Amplification (Reflection) Factor versus Scaled Burst Height (Ref 7, 63).

Positive Duration of Overpressure (sec)

$$(\Delta P)_t = \frac{[(\Delta P)_t]_m}{\overline{C}_z(\overline{P}_z/E_T)^{1/3}} \tag{16}$$

Positive Duration of Material Velocity (sec)

$$G_t = \frac{[G_t/(\Delta P)_t]_m[(\Delta P)_t]_m}{\overline{C}_z(\overline{P}_z/E_T)^{1/3}} \tag{17}$$

Positive Duration of Overdensity (sec)

$$(\Delta\rho)_t = \frac{[(\Delta\rho)_t/(\Delta P)_t]_m[(\Delta P)_t]_m}{\overline{C}_z(\overline{P}_z/E_T)^{1/3}} \tag{18}$$

Blast Efficiency Factor

Scaling methods are very useful tools for finding blast effects levels but there are limitations to be considered. The blast phenomenon is hydrodynamic in nature and therefore the methods presented here are not useful for very early times when the dominant mode of energy transport is radiation. Also, at higher altitudes there is not a clear separation of the shock front from the radiation phase before much of the energy is dissipated. A blast efficiency factor (Fig. 4) was developed from data obtained by runs of the SPUTTER hydrodynamic code at AFWL, Kirtland AFB, New Mexico (Ref 7, 31-32). The blast efficiency factor, when applied to the burst yield, can extend accurate blast calculations from 60,000 to 150,000 ft.

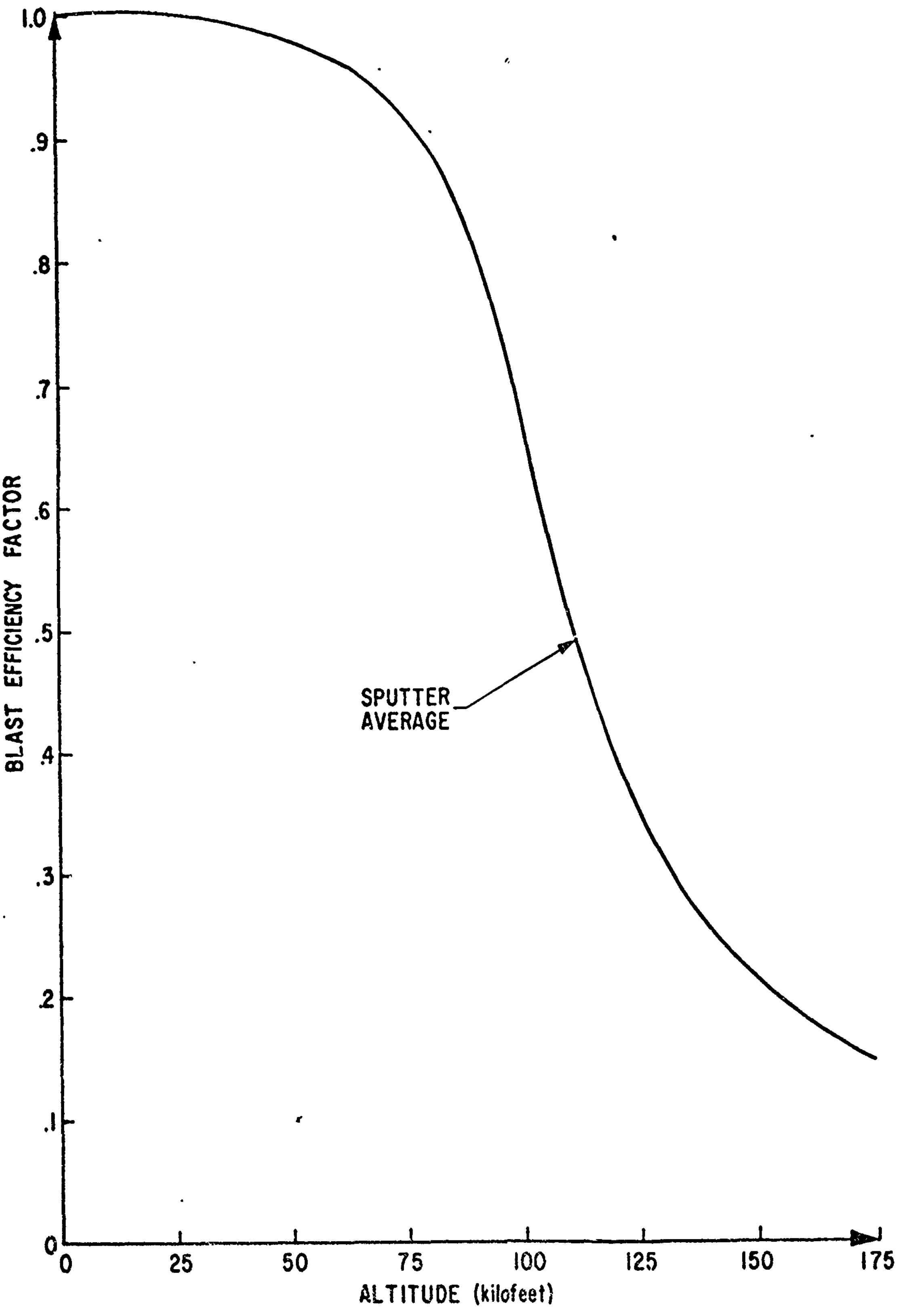

Fig. 4. Blast Efficiency as a Function of Burst Altitude (Ref 7, 33).

Subroutine for Blast Effects

Subroutine BLAST1. The subroutine for calculation of blast parameters and for evaluation of system survivability to blast effects is BLAST1. This subroutine is called by the program GUIDE and returns to GUIDE a record of those vehicles that have been destroyed by blast effects. Shock parameters at the point of vehicle and shock intercept are computed by the methods presented earlier in this chapter. Survival of each vehicle is based on the vulnerability criteria of dynamic pressure and/or overpressure.

Parameters Computed. The results of the blast computation for each burst are printed from the BLAST1 routine. All vehicle losses are listed under "Results of Blast Effects Computations." The lethal level and the type of pressure responsible for each vehicle loss is also printed. The following is also printed out if the option for data is specified:

Height of receiver at shock intercept	(ft)
Slant range at shock intercept	(ft)
Time of shock arrival	(sec)
Shock front velocity	(ft/sec)
Peak dynamic pressure	(psi)
Peak overpressure	(psi)
Peak material velocity	(ft/sec)
Peak overdensity	(slugs/ft^3)
Positive duration of overdensity	(sec)

Positive duration of overpressure (sec)

Positive duration of material velocity (sec)

<u>Sub-Programs Called by BLAST1</u>. Sub-programs TRIPNT, ATMOS, SETUP, MACURE, and MOTION are called from the routine BLAST1. Subroutine TRIPNT establishes the fused shock region for bursts near the surface of the earth. TRIPNT also determines a yield amplification factor for vehicles in the fused shock region. The ATMOS subroutine provides needed atmospheric data from the ARDC standard atmosphere. SETUP and MACURE are table lookup routines that are capable of interpolation and extrapolation from tables of data. The tables of data are stored in the BLOCK DATA section. The programs TRIPNT, ATMOS, SETUP, and MACURE were a part of the SABER code and are described in AFWL-TR-70-85, (Ref 7).

Sub-program MOTION is called from BLAST1 to find the point of vehicle, shock front intercept. Since the shock front moves outward at speeds near the speed of sound, the change in vehicle position during shock front propagation is important.

The model for finding the intercept point by vector methods is presented below. Initially, the scaling laws are used to establish the shock front velocity based on the vehicle position at the burst time. The shock and vehicle positions after a time increment ΔT will establish a closing rate

$$CR = \frac{\Delta S}{\Delta T} \tag{19}$$

where

CR = closing rate

ΔS = change in separation distance, (shock to receiver)

ΔT = time increment

A predicted time increment, ΔT_p, for intercept is then given by

$$\Delta T_p = \frac{SD}{CR} \tag{20}$$

where

SD = separation distance

The intercept point and the shock parameters are finally obtained through an iterative process involving the predicted time increment. The no-intercept case will be indicated by increasing separation distances with each time increment.

Limitations on Blast Calculations. The data base from which blast parameters are calculated is the free-air, sea-level, 1-KT test model. The range of altitudes which can be spanned by scaling techniques is limited. The application of a blast efficiency factor extends the range of accurate calculation from 60,000 ft. to approximately 150,000 ft. The program can calculate results up to 250,000 ft. but no verification is available. Calculations made in the fused shock region are based on a flat reflecting surface and variations from this case may have indeterminate effects on the actual overpressure values. Also, it is important to realize in evaluating results that the scaling techniques do not hold for regions in and on the boundary of the fireball.

This is true because the scaling techniques are not applicable in regions where radiation is the primary means of energy transport (Ref 7, 31).

Accuracy of Blast Calculations. Subroutine BLAST1 computes blast parameters using the same techniques that are used in the SABER code. The calculated results will be the same for the two programs. A correlation between SABER results and the SAP hydrodynamic code has been made (Ref 7, 42-46). The results of that correlation are presented in Figs 5, 6, and 7. The first two figures are for the coaltitude case and the last figure is non-coaltitude for verification of the correction for the nonhomogeneous atmosphere. An additional correlation of SABER results to measured values from actual tests is presented in the appendix of Ref 7. The close correlation of SABER results to the extremely accurate hydrodynamic calculations indicates that the scaling techniques which are employed are adequate to represent the blast phenomenon.

Summary

The methods of blast effects computations were drawn from AFWL-TR-70-85 (Ref 7). The approach includes an accounting for inhomogeneous atmosphere, fused shock region, blast efficiency, and receiver motion. Scaling techniques and empirical data form the basis for all the blast parameter calculations.

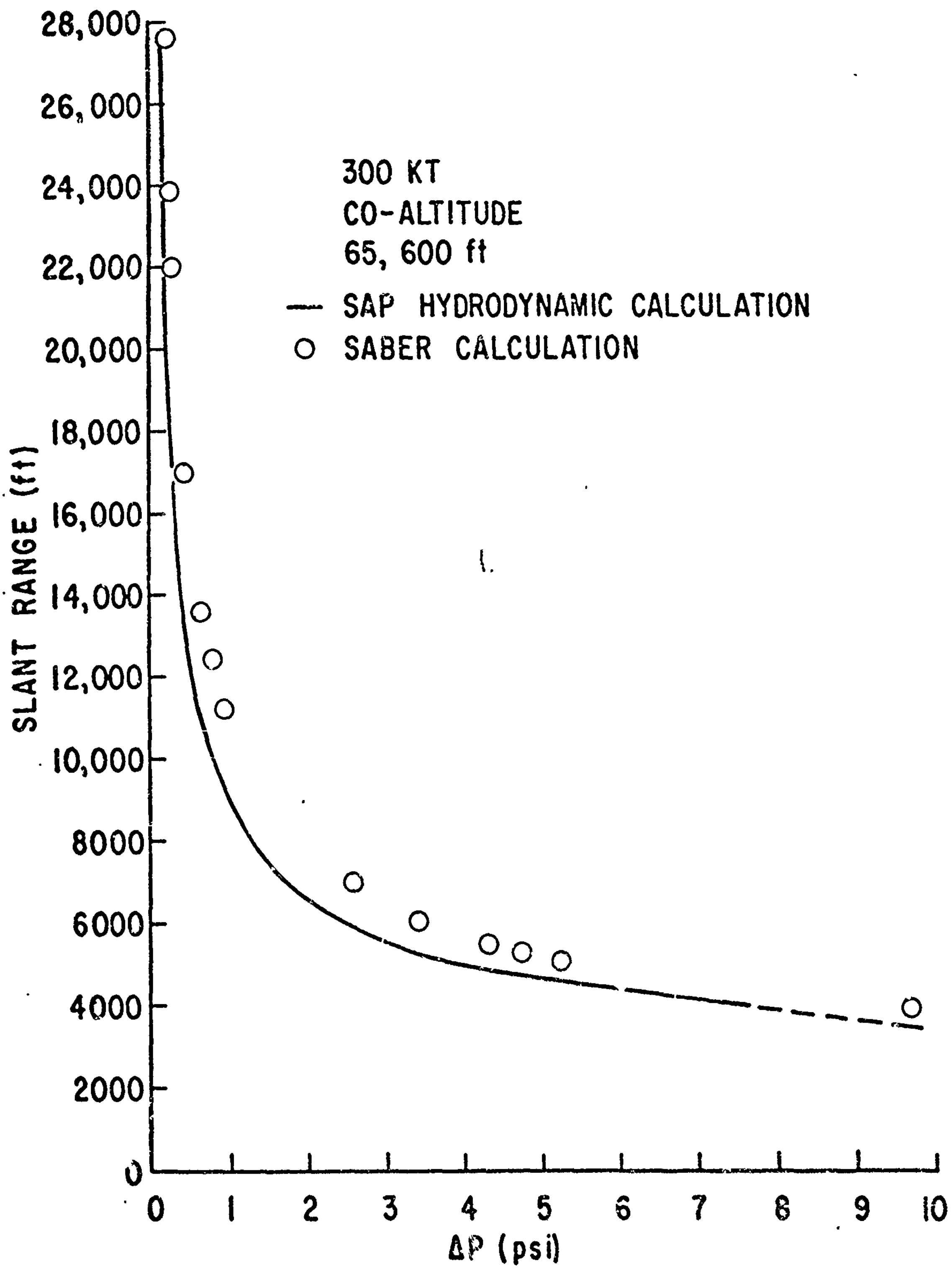

Fig. 5. Comparison of SABER and SAP Results for 300 KT at 65,000 feet (Ref 7, 43).

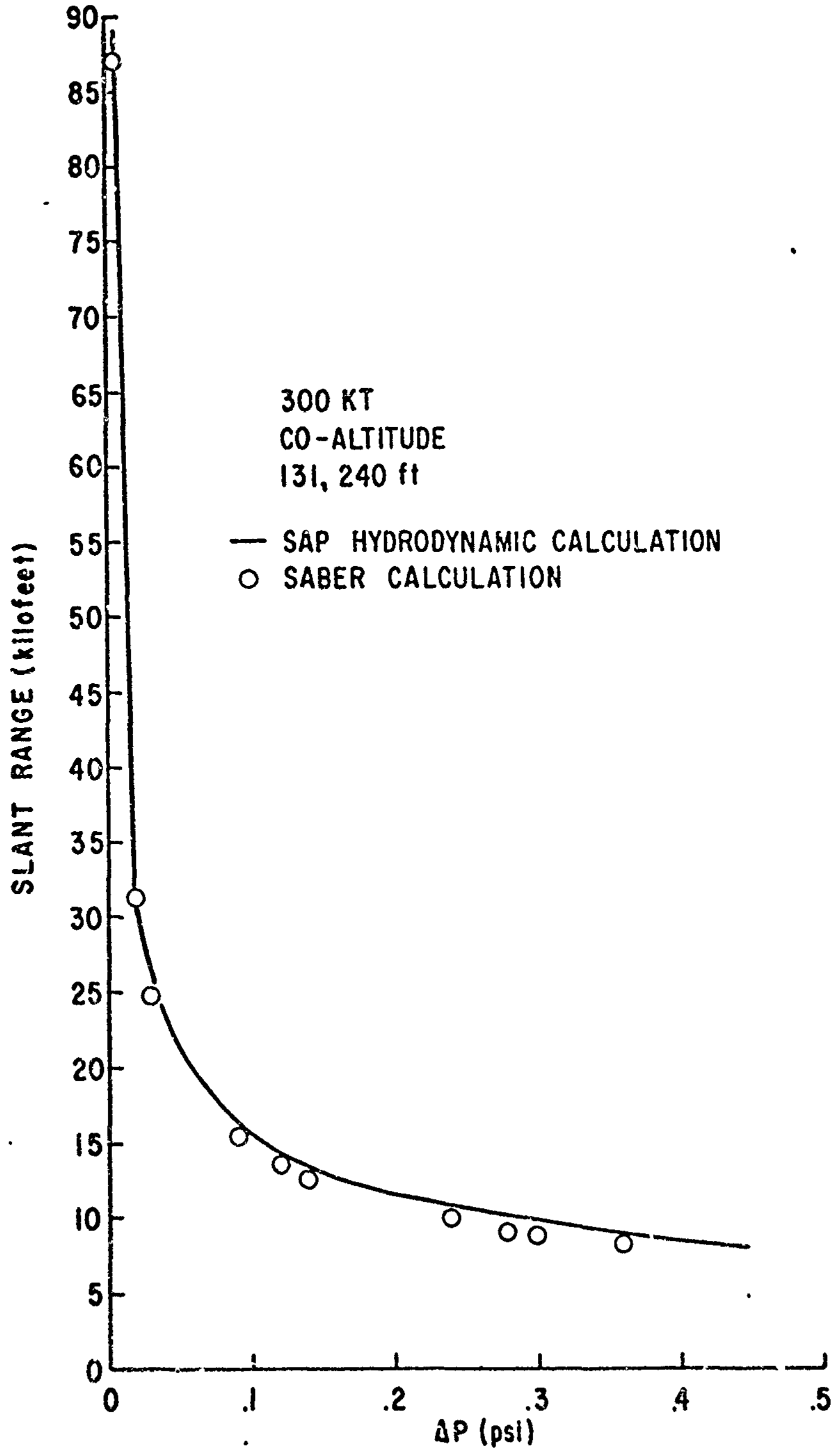

Fig. 6. Comparison of SABER and SAP Results for 300 KT at 131,240 feet.

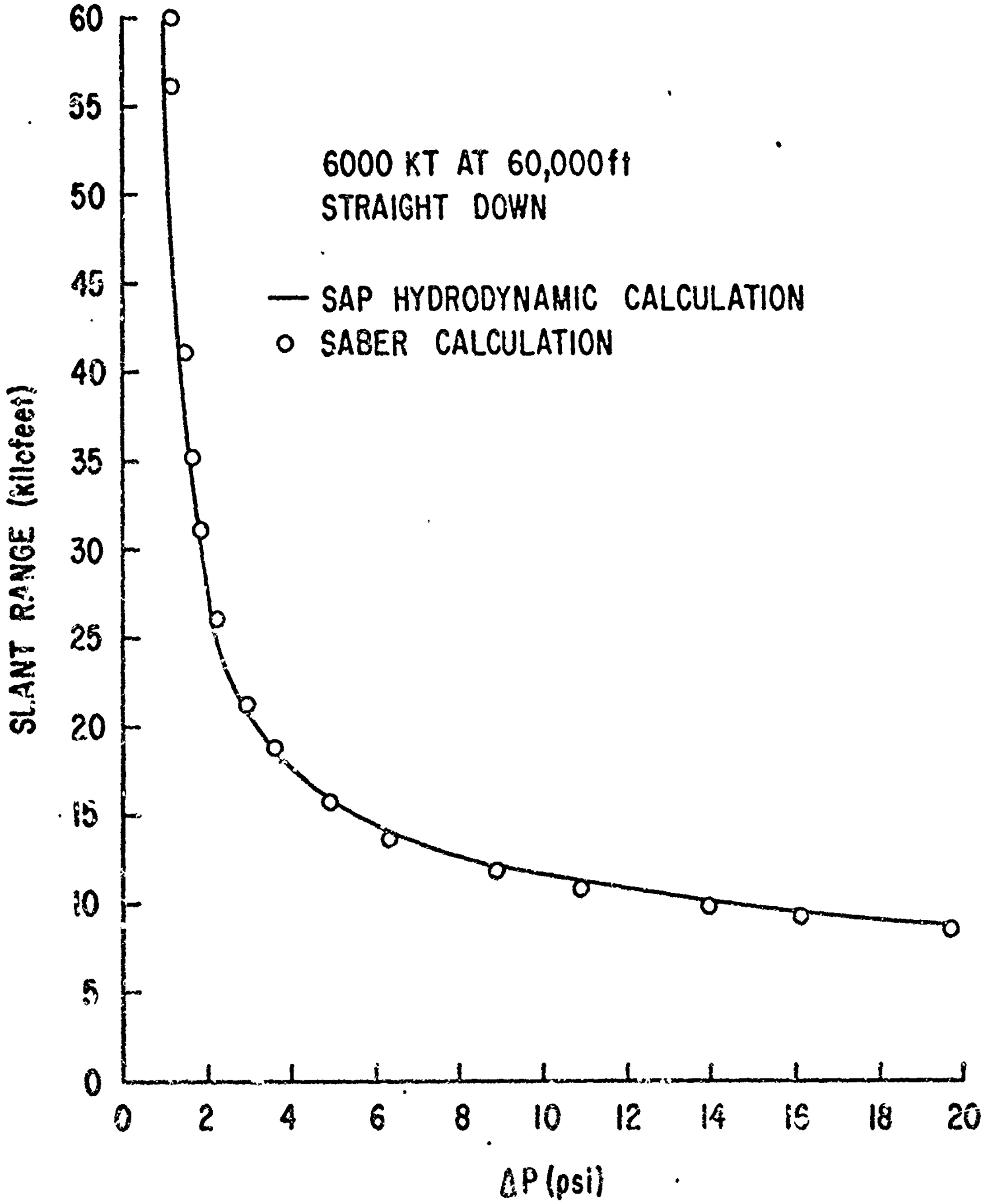

Fig. 7. Comparison of SABER and SAP Results for 6 MT at 60,000 feet (Ref 7, 46).

A subroutine named BLAST1 was developed to make the effects calculations and to perform the system survivability analysis. Survivability is based on the threat levels and vulnerabilities to peak overpressure and peak dynamic pressure. The subroutine is capable of evaluating blast effects up to 250,000 ft.

IV. Computation of Thermal Environments

Thermal Phenomenon

The investigation of thermal effects of nuclear weapons on systems depends on three basic factors. They are the source of thermal energy, the transmission of that energy through a medium, and the absorptivity of a receiver in that medium. The scope of this study is limited to the consideration of the first two factors.

Analysis of the thermal environment is at best an approximate effort. This is so because of the variability from day to day and hour to hour of atmospheric properties which affect the energy transport. Consequently, there is no single approach that can account for all the factors and geophysical conditions. Simplified model environments have been developed from which results should be carefully evaluated. The method presented in this report is such a model.

The first topic treated here describes the determination of the thermal yield. The remaining paragraphs describe the methods used to determine thermal fluence levels depending on the location of both the burst and the receiver. A method is presented to determine thermal levels of both reflected and direct energy for burst altitudes less than 30 kft. with receivers below 100 kft. There is no change in the approach for bursts between 30 and 50 kft. except that reflected energy is negligible in this region. Procedures and relations

have been included which are applicable to the case of a burst above 50 kft. with the receiver below 50 kft. Finally, the case for both burst and receiver above 50 kft. is treated.

<u>Thermal Yield</u>

The thermal yield is a function of the altitude of burst and the total yield of the weapon. In general, the thermal yield is a fraction of the total yield and this fraction rises with increasing altitude and then drops to nearly zero around 350 kft. (100 km). The low and intermediate altitude burst (< 100 kft.) is characterized by two distinct thermal pulses, the second of which contains the bulk of the thermal energy. At higher altitudes the first and second pulse combine to form a single pulse of very high intensity and short duration.

Data from the SPUTTER AFWL weapons effects code has provided the thermal efficiencies for a range of burst yields and altitudes. An empirical relation, a function of altitude alone, has been obtained from the collapsed SPUTTER data and is plotted in Fig. 8. Relations for thermal efficiency and thermal yield were furnished from unpublished information, courtesy of Mr. A. Sharp of AFWL, Kirtland AFB, New Mexico. The thermal efficiency, T, is given by

$$T = e^{(-.3579 - .008H + 7.136 \times 10^{-4}H^2)2.30} \times$$

$$e^{(-1.25 \times 10^{-5}H^3 + 6.42 \times 10^{-8}H^4)2.30} \qquad (21)$$

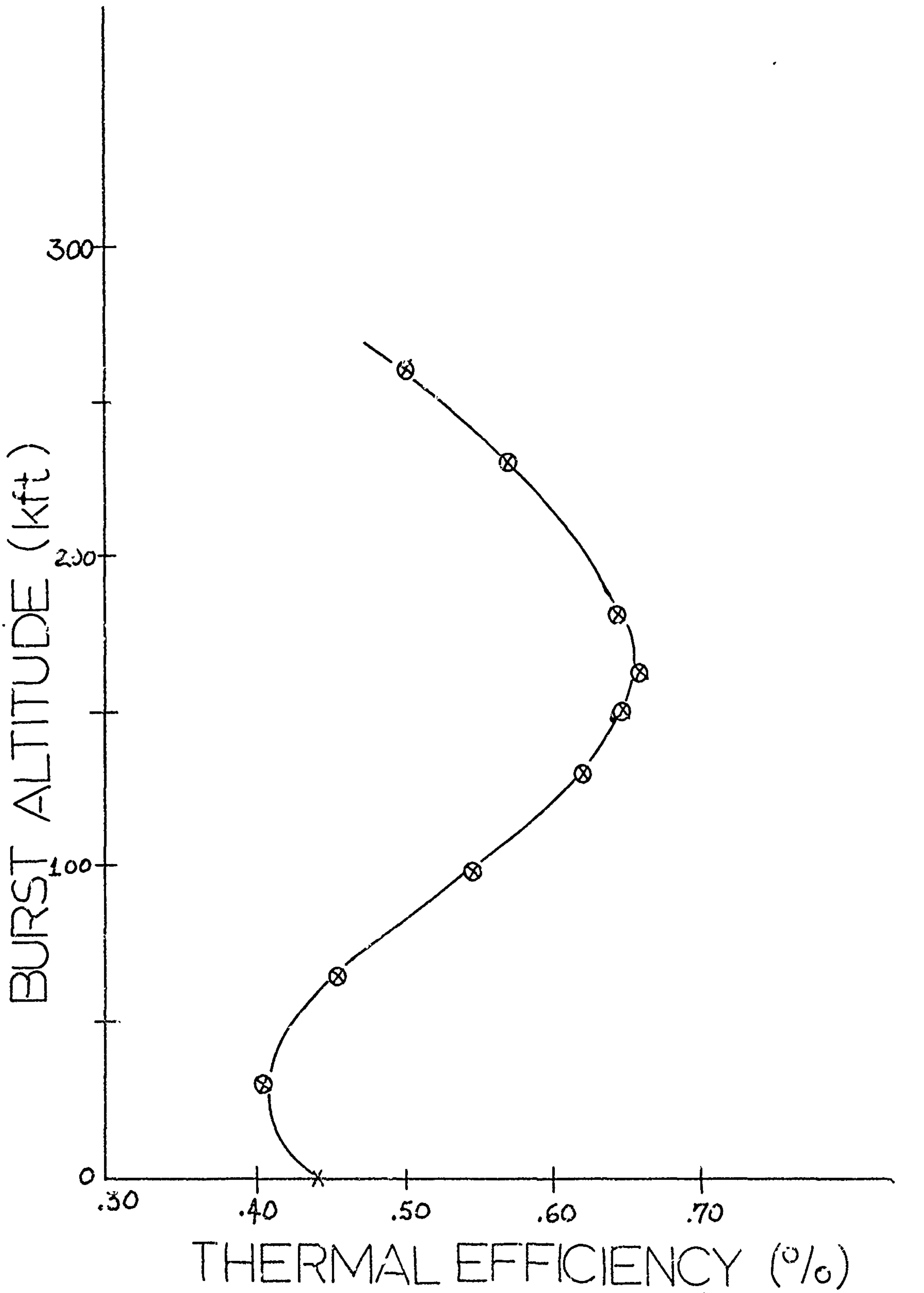

Fig. 3. Thermal Efficiency versus Altitude of Burst.

where

H = height of burst (Km)

The thermal yield (air burst) is given by

$$W_{th} = TW^{.94} \tag{22}$$

where

W = total yield in KT

The thermal yield (ground burst) is

$$W_{th} = .35W^{1.03} \tag{23}$$

The time of the second thermal peak (maximum power output) is taken as the time at which all the thermal energy is released. An empirical relation for that time is given by (Ref 2, 175)

$$T(sec) = .0491(Wn)^{.42} \tag{24}$$

where

n = ratio of air density at burst altitude to that at sea level

Atmospheric Transmission (Burst < 50 kft.)

A model for transmission of thermal radiation in the atmosphere has been developed in Ref 3. That model is presented below and is followed exclusively for thermal calculations except as noted by individual references.

Six basic assumptions are:

1. The fireball of an air burst is essentially spherical and is treated as a point source black body radiator

at 6000 degrees Rankine. The fireball for the surface burst is treated as a hemispherical Lambert-type emitter of uniform temperature. The black body temperature is taken as 3000 degrees Rankine.

2. The transmission of visible energy is evaluated for a collimated beam of energy. This assumption is made for the purpose of describing the geometric path of reflected energy and to allow application of Lambert's Law.

3. The visible energy is assumed to pass through a non-absorbing but scattering media.

4. Attenuation of infrared energy is assumed to be the result of absorption by the water vapor in the atmosphere.

5. The terrain surface is taken as a Lambert plane, infinite and flat.

6. The albedo, or surface reflection factor, is known and is the same for all frequencies of the reflected energy (see Table I on the next page).

An application of Lambert's Law was made to yield an analytic expression for the reflected thermal energy. Lambert's Law expresses the intensity of reflected radiant energy as a function of the angle from which it is viewed (Ref 1, 111-112). The surface of reflection is taken as a black body radiator and as a perfectly scattering surface.

Table I

Values of Albedo for Earth Surfaces

Surface	Reflectance (per cent)
Desert	24-28
Fields (Various Types)	3-40
Forest (Green)	3-20
Grass (Various Conditions)	14-47
Ground (Bare)	7-30
Snow	65-89
Water (Average)	10
Rough Water (White Caps)	10-31
Shock-Frothed Water	40-80
Sand (Dry)	18-28
Sand (Wet)	9-19

(Ref 3, 54)

Reflected Radiation (Air Burst). The thermal fluence of an air burst reflected to a plane horizontal receiver from an infinite Lambert plane is given by

$$Q_R = \left(\frac{W_{th}}{4\pi S^2}\right) T_t \rho[\gamma(H_{Ro}, X_{Ro})] \tag{25}$$

where

Q_R = reflected thermal fluence (cal/cm^2)

S = slant range, ground zero to receiver (cm)

T_t = atmospheric transmission fraction

ρ = albedo

$\gamma(H_{Ro},X_{Ro})$ = gamma function for air burst, (a function of scaled height of the receiver and the scaled x-coordinate range of burst to receiver)

The gamma function has been evaluated by numerical techniques for a range of values of H_{Ro} and X_{Ro}. Both H_{Ro} and X_{Ro} are scaled by the height of the burst above the ground level. The gamma function described above is not to be confused with the well known γ function of mathematics.

Reflected Radiation (Ground Burst). The thermal fluence of a ground burst reflected to a plane horizontal receiver from an infinite Lambert plane has been developed in Ref 4 and is given by

$$Q_R = \left(\frac{W_{th}}{2\pi S^2} \right) T_t \rho[\gamma(S_o,\phi)] \qquad (26)$$

where

$\gamma(S_o,\phi)$ = gamma function for ground burst, (a function of the scaled slant range and the angle ϕ).

The gamma function has been evaluated numerically for ranges of the two variables S_o and ϕ (Ref 4, 288). The slant range, S, is scaled to the radius of the fireball and ϕ is the angle between the vertical at the receiver and the slant range to ground zero. The thermal fluence obtained for both the air and the surface burst is that for normal incidence on a plane

horizontal receiver. Equations (25) and (26) are applicable for burst heights up to and including 30 kft.

Direct Radiation. The thermal fluence directly incident on a plane horizontal receiver is attenuated both by radial divergence and by the transmissivity of the intervening atmosphere. The incident thermal fluence (cal/cm^2) for an air burst is given by

$$Q_D = \frac{W_{th}}{4\pi(SR)^2}(T_D) \qquad (27)$$

where

T_D = direct thermal energy transmittance

SR = slant range, burst to receiver (cm)

W_{th} = thermal yield (KT)

The incident thermal fluence (cal/cm^2) from a surface burst is given by

$$Q_D = \frac{W_{th}}{2\pi(SR)^2}(T_D) \qquad (28)$$

The normally incident fluence may be found by multiplying equations (27) and (28) by the appropriate trigonometric relations.

Transmissivity Fractions. Thermal fluence for bursts below 50 kft. is composed primarily of visible and infrared energy. Transmission of the two energy types is treated separately since the visible energy is primarily subject to scattering and the infrared energy is primarily subject to

absorption by water vapor. Both forms of radiation are affected by the amount of haze, described as a visibility factor, that is present in the environment.

The following equations give the transmissivity functions for visible light in air free of haze including both coaltitude and non-coaltitude cases (Ref 4, 28-29).

$$\cos \psi = \frac{(Z_r - Z_s)}{SR} \tag{29}$$

$Z_s \neq Z_r$

$$T_r = e^{\left(\frac{-.0875}{\cos \psi} \left[e^{-4.57 \times 10^{-5}(Z_s)} - e^{-4.57 \times 10^{-5}(Z_r)} \right] \right)} \tag{30}$$

$Z_s = Z_r$

$$T_r = e^{\left[-4 \times 10^{-6}(SR) e^{-4.57 \times 10^{-5}(Z_s)} \right]} \tag{31}$$

where

T_r = transmissivity factor (visible)

Z_r = height of receiver

Z_s = height of source

The transmissivity factors for visible light in air with haze present are given by

$Z_s \neq Z_r$

$$T_h = e^{\frac{-16.4}{V \cos \psi} \left[e^{-4.57 \times 10^{-5}(Z_s)} - e^{-4.57 \times 10^{-5}(Z_r)} \right]} \tag{32}$$

$Z_s = Z_r$

$$T_h = e^{\frac{-7.5 \times 10^{-4}(SR)}{V}\left[e^{-4.57 \times 10^{-5}(Z_r)}\right]} \tag{33}$$

where

T_h = transmissivity factor for visible (with haze)

V = visibility at sea level (miles)

The transmissivity factor for infrared energy is dependent on the amount of water vapor present (given in precipitable millimeters of water along the transmission path). The water vapor present in the path is given by

$Z_s \neq Z_r$

$$w = \frac{2.3\ P_o}{\cos\psi}\left[10^{-6.1 \times 10^{-5}(Z_s)} - 10^{-6.1 \times 10^{-5}(Z_r)}\right] \tag{34}$$

$Z_s = Z_r$

$$w = 3.23 \times 10^{-4}(P_o)(SR)\left[10^{-6.1 \times 10^{-5}(Z_s)}\right] \tag{35}$$

where

w = precipitable millimeters of water

P_o = water vapor pressure at sea level (mmHg)

Finally the total transmissivity, T_t, is given by

$$T_t = F_v T_R T_h + F_{ir} T_w (.7 + .3T_h) \tag{36}$$

where

F_v = fraction of thermal fluence in visible region

F_{ir} = fraction in infrared region

T_w = infrared transmission factor

The fractions of visible and infrared energies are functions of the black body temperature. The energy is split evenly between visible and infrared for the 6000 degree air burst. For the ground burst at 3000 degrees, $F_v = .1$ and $F_{ir} = .9$ (Ref 3, 35).

The infrared transmission factor is given as a function of the precipitable water vapor in the transmission path. Curves for both the air and the ground burst are given in Fig. 9.

Combinations of the basic equations presented in this section will allow transmission fractions to be compiled for reflected energy and for situations where there is a haze layer from ground level up to a specified altitude. The interested reader is referred to Ref 3, pp. 56-60.

The High Altitude Burst

Transmission of thermal fluence from a burst above 50 kft. to a receiver below 50 kft. has been developed by a separate approach. The ultraviolet fraction of the thermal energy is a significant portion of the thermal energy for bursts in this region. The thermal fluence incident on a plane horizontal receiver is given by

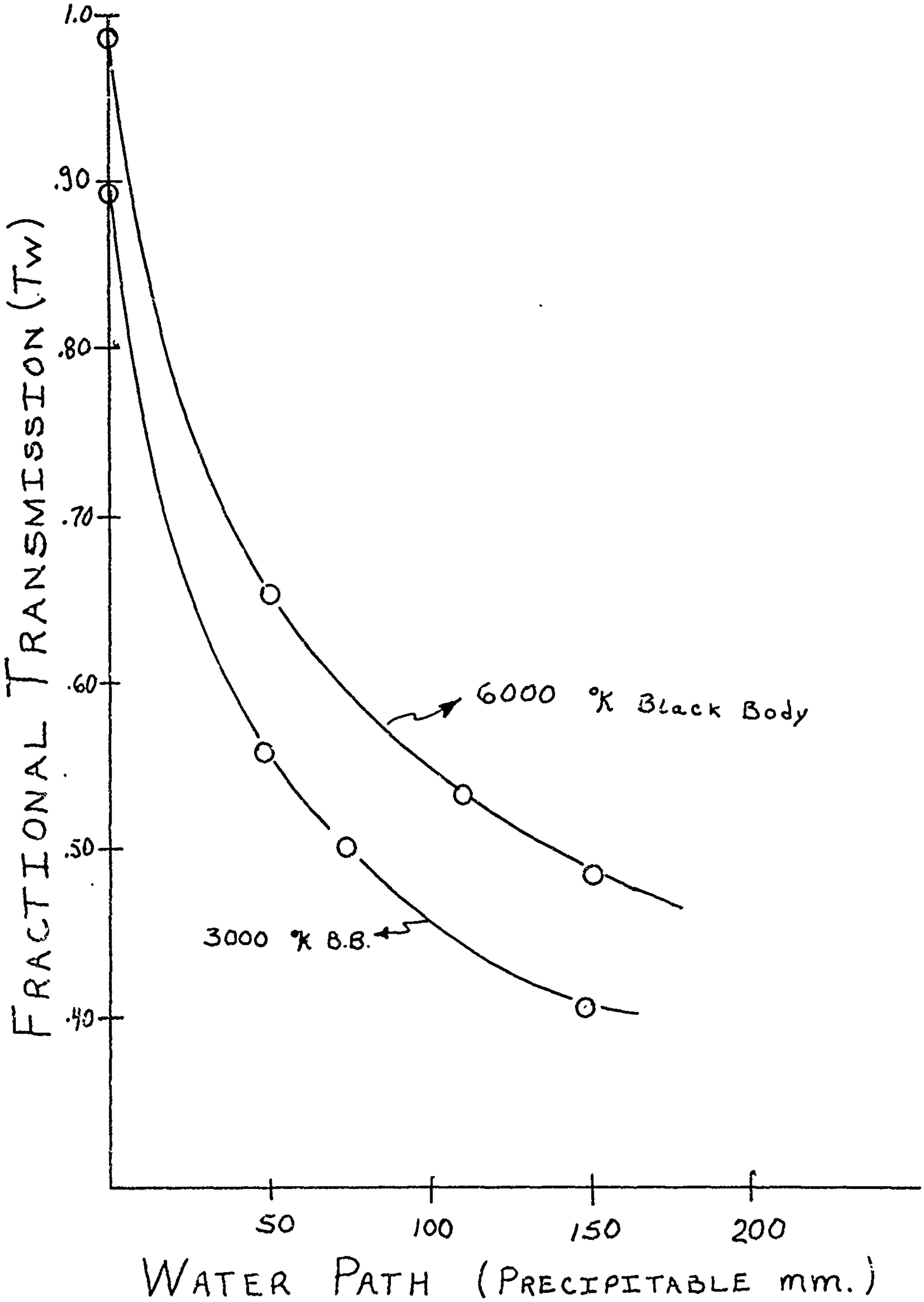

Fig. 9. Fractional Transmission of Infrared Radiation by Water Vapor (Ref 8, 12).

$$Q = \frac{W_{th}}{(Z_s - Z_r)^2} [F_{uv}\, e^{-1.31 \times 10^{-4}(R)} +$$

$$(1 - F_{uv}) e^{-1.31 \times 10^{-5}(R)}] \sin^2 \phi \qquad (37)$$

where

$$\sin \phi = \frac{(Z_s - Z_r)}{SR} \qquad (38)$$

F_{uv} = fraction of ultraviolet energy

and for $Z_r < 28{,}000$ ft. the reduced range, R, is

$$R = \frac{31746}{\sin \phi} [e^{-3.15 \times 10^{-5}(Z_r)} - .414] +$$

$$\frac{9987}{\sin \phi} [1 - e^{-4.55 \times 10^{-5}(Z_s - 28{,}000)}] \qquad (39)$$

and for $28{,}000 < Z_r < 50{,}000$

$$R = \frac{9987}{\sin \phi} [1 - e^{-4.55 \times 10^{-5}(Z_s - 28{,}000)}] \qquad (40)$$

The High Altitude Burst and Receiver

The thermal transmission factor is essentially unity when both the burst and receiver are above 50 kft. Radial divergence is the only attenuation present in this region. The thermal fluence in cal/cm^2 is given by

$$Q = \frac{W_{th}}{4\pi(SR)^2} \tag{41}$$

Subroutine for Thermal Effects

Subroutine THERM. The subroutine for calculation of thermal effects and survivability to those effects is called THERM. This subroutine is called by the program GUIDE and returns to GUIDE a record of those vehicles that have been destroyed. Thermal energy levels are computed at each vehicle position. Survival of each vehicle is based on a comparison of the vulnerability level and the free field thermal energy level.

Reflected energy from the surface of the earth may be significant under certain conditions. A survivability test is also performed based on the sum of the reflected and the direct energy normal to a plane horizontal receiver. This test is made only when the reflected and direct energy is additive, i.e., for a burst below the receiver.

Parameters Computed. The results of the thermal computations for each burst are printed from the THERM routine. All vehicle losses are listed in the output under, "Results from Thermal Effects Computations". The lethal level is also included as printed information. The following additional information is printed if the option for data is chosen:

Unattenuated free field fluence (cal/cm^2)

Height of burst (ft)

Slant range at time of peak radiant power (mi)

Time to peak radiant power (sec)

Direct free field fluence (cal/cm^2)

Direct normally incident fluence (cal/cm^2)
(Normal to a plane horizontal receiver)

Reflected fluence (cal/cm^2)

Reflected plus direct normal fluence (cal/cm^2)
(Computed only if burst below the receiver)

Sub Programs Called by THERM. Subroutines ATMOS, TRANS, SETUP, and MACURE are called from the routine THERM. Subroutine TRANS is called upon to evaluate the atmospheric transmission factors for thermal energy as needed in the thermal calculations. The effect of a haze layer from sea level to any specified altitude is included in the calculation of the transmission factors. The remaining subroutines perform the same functions as described in Chapter III. BLOCK DATA is again used for storage of data tables.

Limitations on Thermal Calculations. Methods have been presented for determining transmission of thermal energy in all altitude ranges. However, the determination of thermal efficiency is accurate only to approximately 250,000 ft. Extrapolation beyond this limit is possible but no verification of accuracy has been made.

Calculation of thermal effects for burst altitudes below 50 kft. include the effect of visibility. The method for finding transmission fractions is accurate for transmission

distances up to and including the visibility range. Thermal levels that are computed for distances exceeding that range are likely to be higher than actual values. Also, the attenuating atmosphere is considered to extend throughout the transmission path for the case of a burst below 50 kft. with the receiver above 100 kft. This assumption will result in some excess attenuation of the thermal energy.

The presence of clouds and stratified layers of haze will greatly affect the thermal energy present at any given point. These effects have not been accounted for. Deviations from the assumptions of this simplified model will nearly always be present and the results should be interpreted accordingly.

Evaluation of Thermal Computations. Thermal levels computed by subroutine THERM have been compared to values computed by the thermal code SNAPT at AFWL. The codes are based on a similar theoretical approach. A correlation of free field thermal levels was made for a range of burst altitudes from 0 to 60,000 ft. and for receivers from 0 to 50,000 ft. Agreement to within 10% of the SNAPT values was obtained except for the ground burst case where the THERM values were a factor of two times greater than those of SNAPT. A different approach was used in the two codes for the determination of thermal yield for the ground burst. The SNAPT approach is intended to account for a high attenuation factor near the earth's surface and is probably more correct in that region.

The method for prediction of thermal fluence levels in the lower altitude regions (below 50 kft.) has been correlated to actual tests. There is general agreement to within ± 10% for those conditions meeting the assumptions presented in this report. The calculations for a high altitude burst with a receiver in the attenuating atmosphere (below 100 kft.) are estimated to be correct to within a factor of two. Thermal transmission for the high altitude burst and receiver case is not affected by atmospheric attenuation. Radial divergence is applied to find the thermal level and the accuracy is only limited by the prediction of thermal yield.

Summary

The methods of thermal effects computations were drawn primarily from Ref 3. The transmission fractions were found by separate techniques for three regions of altitude. The regions handled separately were the following: burst altitudes less than 30 kft. with receivers below 100 kft., burst altitudes above 50 kft. with receivers below 50 kft., and both burst and receiver above 50 kft.

A subroutine named THERM was developed to make the effects calculations and to perform the survivability analysis. Survivability is based on the threat level and vulnerability for the free-field thermal fluence in cal/cm^2. The subroutine is capable of evaluating thermal effects for bursts up to approximately 250,000 ft.

V. Results and Conclusions

A computer code has been developed that will provide a method to make survivability studies on systems that are undergoing a nuclear attack. Initially, subroutines have been included to evaluate survivability of systems to the effects of blast and of thermal energy. The code is designed to readily accept similar subroutines for the evaluation of other nuclear burst effects.

The program was prepared for use on the CDC 6600 computer with a Scope 3.3 compiler version. The code is written in the FORTRAN EXTENDED language. Core memory required on the CDC system is approximately 40,000 octal words and run times are on the order of a few seconds.

The code is capable of handling from one to ten sequential bursts which are automatically targeted and, of evaluating nuclear effects on a maximum of 100 vehicles. The number of bursts which may be entered with positions specified by the user is not limited. Any type of system may be studied for which the vulnerability limits are known.

Subroutines for the separate effects each have separate limitations. The user of this program should be familiar with those limitations to obtain the most accurate results. The results from blast computations have been correlated to actual tests and to hydrodynamic calculations. A close agreement has been verified for all regions up to altitudes of 150,000 feet. The accuracy of calculations for thermal

effects varies depending on the altitude of the burst and receiver combination. Some correlation to actual test data has been made and a close agreement was found between this thermal routine and the SNAPT, AFWL routine. The values for free field blast and thermal effects computed by this code should be considered adequate for systems analysis and survivability considerations. A sample problem which illustrates the use of this code has been included as Appendix E.

The presence of clouds, temperature inversions and other atmospheric variations can have a significant effect on both blast and thermal levels. Also deviations from the assumed flat reflecting surface of the earth are important for the lower altitudes. These factors should always be recognized in conjunction with an interpretation of results.

Some areas of this code that could be further investigated or improved upon include the following items. The capabilities of the thermal effects evaluation could be improved by accounting for the effects of reflected thermal energy from cloud layers above the point of interest. The additive effects of free field levels for coincident bursts has not been treated and could be a significant factor for closely spaced bursts. No provision has been made to evaluate the environment of special weapons. This capability could be very important in survivability evaluations and is a desirable addition to the code. The development of subroutines to calculate environments for x-ray, gamma ray, neutrons, and Electro-Magnetic Pulse should also be

accomplished. This addition to the basic survivability code, along with the blast and thermal subroutines, would then provide a single package to evaluate survivability to each of the major nuclear effects.

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Appendix A

A Statistical Approximation for a Normally Distributed Variable

The Central Limit Theorem of probability theory was used to obtain a normal, spherical distribution for the detonation point relative to the chosen target. This theorem states (Ref 6, 251) that if x_i is a random variable taken from sample size n, then

$$z_n = \frac{\sum_{i=1}^{n} x_i - E[\sum x_i]}{\sqrt{n}\ \sigma_x} \tag{42}$$

where

z_n = value of a random variable which is approximately normally distributed with a mean of zero and a variance of one

$E(x_i)$ = expectation value of x_i

$E(\sum x_i)$ = summation over n, of expectation values

σx = standard deviation for x_i

The coordinates of a normal, spherical distribution may be found in the following manner:

For a value of n = 12 and for random numbers between 0 and 1 we have

$$E[x_i] = 1/2 \tag{43}$$

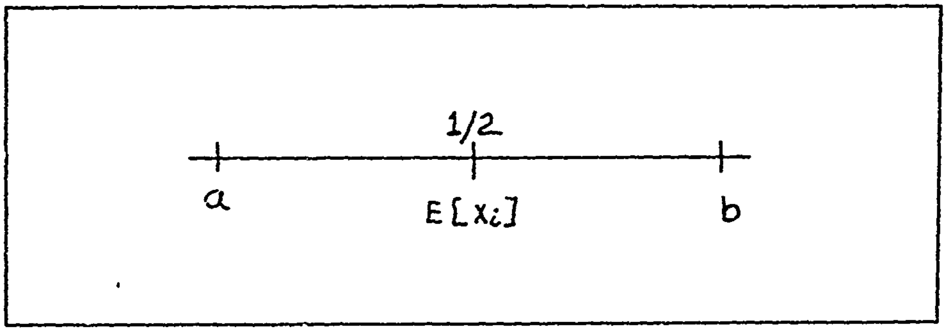

Fig. 10. Schematic Representation of Random Number Distribution.

$$E[\sum x_i] = 12(1/2) = 6 \tag{44}$$

$$\text{Variance} = \sigma_x^2 = \frac{(b-a)^2}{12} = 1/12 \tag{45}$$

$$\text{Std. Dev.} = \sigma_x = 1/\sqrt{12} \tag{46}$$

then

$$\sqrt{n}\ \sigma_x = \sqrt{12} \cdot 1/\sqrt{12} = 1 \tag{47}$$

and the approximately normally distributed random variable is given by

$$z^j = \sum_{i=1}^{12} x_i - 6 \tag{48}$$

This value, z^j, has been determined for a distribution of variance of one. A specified spherical probable error, spe, then delineates the distribution. The value, z^j, must be scaled by the appropriate standard deviation. The spherical distribution has

$$\sigma = \sigma_x = \sigma_y = \sigma_z \tag{49}$$

and

$$spe = 1.538\sigma \qquad \text{(Ref 5, 301)} \tag{50}$$

therefore

$$\sigma = \frac{spe}{1.538} \tag{51}$$

Finally, for a given distribution, A, an approximately normally distributed point, (x,y,z) is given by

$$(x,y,z) = \sigma_A(z^{(1)}, z^{(2)}, z^{(3)}) \tag{52}$$

Appendix B

Index of Variables (Major Routines)

Note: Variables are defined in the first routine in which they appear and are not listed again.

Program GUIDF:

Variable Name	Definition	First Appearance (Line)
BURSTX BURSTY BURSTZ	Coordinate points of the burst position	9
CYCLE	Number of bursts to be analyzed	13
COUNT	Record of burst number currently under analysis	13
DISPX DISPY DISPZ	X,Y,Z displacements, burst to receiver position	125 126 127
DISPR	Radial displacement, burst to receiver	128
HG	Height of ground above sea level	8
HB	Height of burst above sea level	8
HZ	Height of receiver above sea level	8
II	Number of vehicles input	6
IODAT	Input parameter for data print option	6
IRC	Integer number to precycle the random number generator	102
KTEMP	Input parameter for non-standard temperature option	6
NUM	Array of possible values for IRC	12
OPT1	Option for method of burst placement	13
OPT2	Option to change velocity vectors	13

GUIDE (cont.)

Name	Definition	Line
PO	Water vapor pressure at sea level	11
POSX POSY POSZ	X,Y,Z arrays for vehicle positions	10 10 6
RFB	Radius of fireball	70
RHO	Albedo	11
SPE	Spherical probable error for targeting	89
TARGX TARGY TARGZ	X,Y,Z coordinate points on which burst is targeted	92 93 94
TEMPS	Nonstandard sea level temperature (degree Rankine)	6
TIMEX	Incremental time for each burst	48
TM(1)	Temperature at receiver altitude (degree Rankine)	6
TM(2)	Temperature at ground altitude (degree Rankine)	6
TM(3)	Temperature at burst altitude (degree Rankine)	6
VBLASTI	Vulnerability level for overpressure	6
VEHIC	Array for record of vehicles	6
VGAMA	Vulnerability level for gamma	45
VIS	Visibility at sea level (miles)	11
VNEUT	Vulnerability level for neutrons	45
VQ	Vulnerability level for dynamic pressure	45
VTHERM	Vulnerability level for thermal energy	45
VXRAY	Vulnerability level for x-ray	45

GUIDE: (cont.)

Name	Definition	Line
VX VY VZ	X,Y,Z velocity component vectors for each vehicle	10
W	Yield in KT	8
ZH	Height of haze layer above sea level (ft.)	11

Subroutine TARGET:

Name	Definition	Line
DUM	Dummy variable for argument of random number function	9
R	Radial displacement of burst from target position	29
RX1 RY1 RZ1	X,Y,Z coordinate displacement of burst from target position	26 27 28
SIGMA	Standard deviation for a normal distribution	7
SUMX SUMY SUMZ	Computational sum:	3 4 5
X Y Z	X,Y,Z coordinates of the target point	1

Subroutine BLAST1:

Name	Definition	Line
ACF	Table of altitudes for blast efficiency	21
ALFA	Ledsham-Pike α correction factor	132
ALP1E	Minimum angle at which mach reflection will occur (degrees)	13
ALP1ER	ALP1E (radians)	13
CF	Table of altitudes corresponding to table of efficiency factors, CFF (feet)	21

Subroutine BLAST1: (cont.)

Name	Definition	Line
CFF	Table of blast efficiency factors	77
CFS	Separation constant for segments of the scaled range versus overpressure curve for the 1KT model burst	35
CF1 CF2 CF3	Coefficients for empirical fit of α versus overpressure curve	15
CF11 CF22 CF33 CF44 CF55	Coefficients for empirical fit of scaled range versus overpressure curve	30-34
CONT	Variable for program flow	25
C10 C11 C12	Coefficients used in empirical fit of the ratio of scaled positive duration of overdensity to the scaled duration of overpressure versus RBAR, the scaled range	21
C4 C5 C6 C7 C8 C9	Coefficients used in empirical fit of the ratio of scaled positive duration of material velocity to scaled duration of overpressure versus RBAR	21
DELP	Peak overpressure (psi)	25
DEN	Dummy argument in ATMOS call	100
DT	Time increment for use in subroutine MOTION	93
EPSILO	Ratio of overpressure to pressure at the receiver	134
FLAG	Variable controlling program flow	91
FR	Yield amplification factor for fused shock calculation	13

Subroutine BLAST1: (cont.)

Name	Definition	Line
H(1) H(2) H(3)	HZ, HG, HB respectively	27
HT	Height above ground of point on triple-point path (kft)	24
INCOMP INTC KCASE	Variables controlling program flow	64 90 72
KER	Variable indicating error in ATMOS	100
LER	Dummy argument in call to MACURE	77
NIT	Variable for program flow	59
P(1) P(2) P(3)	PZ, PB, PG respectively (set in equivalence statement)	27
PB	Pressure at burst altitude (psi)	13
PBPZ	Ratio PB/PZ	13
PBR	Ratio PB/PSL	13
PBRW	(PBR/W)**. 3333	13
PDMV	Positive duration of material velocity (sec)	169
PDOD	Positive duration of overdensity (sec)	171
PDOOP	Positive duration of overpressure (sec)	167
PG	Pressure of ground elevation (psi)	13
PGR	Ratio PG/PSL	13
PHIR	Angle used in triple point consideration	13
POD	Positive overdensity (slugs/ft^3)	170
PR(1)	Ratio P(1)/PSL) (PZR)	27

Subroutine BLAST1: (cont.)

Name	Definition	Line
PR(2)	Ratio P(2)/PSL (PGR)	27
PR(3)	Ratio P(3)/PSL (PBR)	27
PSL	Atmospheric pressure at sea level (psi)	58
PZ	Atmospheric pressure at receiver (psi)	13
PZR	Ratio PZ/PSL	13
R	Radius of the fireball (kft)	13
RA	Slant range from burst to point on triple-point path (kft)	13
RBAR	Scaled range (1 KT, sea level burst) (kft)	124
RHO(1) RHO(2) RHO(3)	Density at HZ, HG, HB respectively (slugs/ft^3)	100
RHOB RHOG RHOZ	RHO(3), RHO(2), RHO(1) respecti[illegible]	28
SDELP	Scaled peak overpressure [illegible]o 1 KT, sea level burst (psi)	126
SEPD	Separation distanc[illegible] [illegible]hock front to vehicle positio[illegible]	140
SEPDT	Separation distance for time increment DT	140
SFR	Shock front range from burst position	92
SFV	Shock front velocity (ft/sec)	140
SR	Slant range from burst to receiver	56
SRE	Slant range from burst to origin of the triple-point path on ground (kft)	13

Subroutine BLAST1: (cont.)

Name	Definition	Line
SS(1) SS(2) SS(3)	Ambient speed of sound at receiver, at ground, and at burst altitudes respectively (ft/sec)	27
SSB SSG SSZ	SS(3), SS(2), SS(1) respectively	28
SSZR	Ratio of speed of sound at receiver to that at sea level	114
ST	Horizontal range from ground zero to point on triple-point path (kft)	69
STO	Horizontal range from ground zero to the beginning of triple-point path (kft)	67
TAB(ALL)	Tabular data stored in BLOCK DATA	18
TAB1I	Values of scaled range, RBAR, (Independent Variable)	
TAB1D	Values of scaled peak overpressure, SDELP (Dependent Variable)	
TAB2I TAB2D	Values of scaled range, RBAR Values of Ledsham-Pike alpha correction	
TAB3I TAB3D	Used to invert order of entry of values in TAB1	
TAB4I TAB4D	Values of angle ALPHIR Values of angle PHIR	
TAB5I TAB5D	Values of scaled height of burst Values of yield amplification factor for Mach stem region	
TAB6I TAB6D	Values of scaled range, RBAR Values of scaled time of shock arrival	
TDPZ	Scaled positive duration of overpressure	154
TDRZ	Ratio of scaled positive duration of overdensity to the scaled duration of overpressure	166

Subroutine BLAST1 (cont.)

Name	Definition	Line
TEMP	Dummy argument for ATMOS call	100
TMV	Ratio of scaled positive duration of material velocity to scaled duration of overpressure	161
TR	Dummy variable in ATMOS call	100
TSA	Time of shock arrival (sec)	139
TSACAP	Time of shock arrival (scaled, 1 KT sea level burst)	138
TT	Dummy argument in MOTION call	140
UL(ALL)	Separation blocks for ranges of the curves of positive phase duration versus RBAR	21
VC	Dummy variable in ATMOS call	100
WOR	Yield, W	49
XITER		25
XKKX	Variables controlling program flow	24

Subroutine THERM:

Name	Definition	Line
AAA1	Table of independent variables normalized slant range and angle, PFE	10
AAA2	Table of ground burst gamma functions (dependent variable)	10
BB1	Table of variables - HRO and XRO (independent)	10
BB2	Table of gamma functions, air burst (dependent)	10
DELX	X coordinate range, burst to receiver	61
DELZ	Z coordinate range, burst to receiver	62

Subroutine THERM: (cont.)

Name	Definition	Line
FUV	Fraction of thermal yield in ultraviolet	120
GAM	Gamma function for air or ground burst	80
HOB	Height of burst above sea level	20
HRO	Scaled height of the receiver	85
PFE	Angle between the vertical at the receiver and the slant line to ground zero	78
PI	Constant of multiplication	38
PO	Water vapor pressure at sea level (mmHg)	9
PX PY PZ	Vehicle coordinate positions at time of the thermal maximum	58 59 60
QDN	Direct thermal fluence normal to plane horizontal receiver (cal/cm^2)	96
QDFF	Direct thermal fluence, free field (cal/cm^2)	93
QDFFUN	Direct thermal fluence, free field, unattenuated	94
QR	Reflected thermal fluence (cal/cm^2)	90
QMHR	Sum of reflected and direct normal fluence on a plane receiver (cal/cm^2)	99
R	Reduced range (high altitude burst)	123
SRMI	Slant range (miles)	69
SRCM	Slant range (cm)	70
SRN	Normalized slant range	77
SS	Dummy argument in ATMOS call	21

Subroutine THERM: (cont.)

Name	Definition	Line
STHET	Angle used in high altitude burst computations	121
TBW1	Table of precipitable water vapor (independent variable)	10
TBT1	Table for fractional transmission of infrared (ground burst)	10
TBT2	Table for fractional transmission of infrared (air burst)	10
TBV1	Table of height of burst (independent variable)	10
TBV2	Table of fraction of ultraviolet energy (dependent variable)	10
TD	Direct transmission fraction	92
TEFF	Thermal yield efficiency factor	33
TMAXZ	Time of 2nd thermal max. (sec)	30
TMIN	Time of thermal minimum (sec)	29
TR	Reflected transmission fraction	87
TYPE	Variable controlling program flow	86
WMT	Yield in megatons	18
WTH	Thermal yield (KT)	37
XRO	Scaled X range	82

Subroutine TRANS:

CHK	Variable for program flow	1
CTHETA	Angle used in transmission formulas	16
FIR	Fraction of infrared energy	69
FV	Fraction of visible energy	68
LER	Error record	75

Subroutine TRANS: (cont.)

Name	Definition	Line
TH	Transmission factor with haze	19
TR	Transmission, clear air	20
TT	Total transmission factor	79
TW	Transmission factor, infrared	75
XXW	Water vapor in the transmission path	40

Subroutine TRIPNT:

Name	Definition	Line
ALFA	Ledsham-Pike α factor	59
ALPHA ALPHIR ALPIE	Angles used in triple-point computation	 134 107
ALT	Height of burst above ground (kft)	40
ALTSRG	Ratio of ALT to slant range from burst to a point on the ground	89
CAPD CAPQ	Functions for Newton-Raphson iteration to determine ALFA	84 85
CONT	Variable for program flow	125
DDELP	Derivative in Newton-Raphson iteration	64
DELPD	Desired overpressure (Range solution only)	124
DELPG	Overpressure on ground	62
DELPR	Overpressure received, used in iteration process	31
DPDX DRBAR	Derivatives in N-R iteration	75 76
FR	Yield amplification factor (fused shock region)	46
INCOMP	Variable recording error in input data (Range solution only)	95

Subroutine TRIPNT: (cont.)

Name	Definition	Line
PHIR	Angle used in triple-point calculations	136
PPP	Exponent used in functional curve	68
SHB	Scaled height of burst	42
SMF	Function used in Newton-Raphson iteration	83
XI	Incremental value of shock strength	54
XITER	Variable for program flow	31
XK		48
XKK	Variables for program flow	127
KKK		128

Appendix C

Details of Data Entry

Input data cards are to be prepared by the following instructions.

Column	Format	Symbol	Input	Comments
CARD 1				
1-12	E12.5	VIS	-	The visibility in miles at sea level
13-24	E12.5	PO	-	The water vapor pressure in mmHg at sea level
25-36	E12.5	RHO	-	The albedo factor (a decimal fraction)
37-48	E12.5	ZH	-	Altitude of haze layer (ft. above sea level)
CARD 2				
1-3	I3	II	-	Integer, number of vehicles to be entered in the vehicle array (right justified)
4-6	I3	CYCLE	-	Integer, number of weapon bursts (right justified)
CARD 3				
1	I1	KTEMP	0	Option for use of standard atmosphere (remainder of Card 3 is blank for this value of KTEMP)
		KTEMP	1	Option for nonstandard atmosphere (complete Card 3 as shown below)
2-7	F6.0	TEMPS	-	Desired temperature at sea level in degrees Rankine

Column	Format	Symbol	Input	Comments
CARD 3				
8-13	F6.0	TM(1)	-	Temperature at altitude of receiver (degrees Rankine)
14-19	F6.0	TM(2)	-	Temperature at height of ground (degrees Rankine)
20-25	F6.0	TM(3)	-	Temperature at height of burst (degrees Rankine)
CARD 4 (Multiple card)				
1-12	E12.5	POSX(I)	-	X coordinate position in feet for vehicle I
13-24	E12.5	POSY(I)	-	Y coordinate position in feet for vehicle I
25-36	E12.5	POSZ(I)	-	Z coordinate position in feet for vehicle I
				(Coordinate points for each vehicle are relative to an arbitrarily established origin of coordinates at sea level.)
37-48	E12.5	VX(I)	-	X component of velocity in ft/sec for vehicle I
49-60	E12.5	VY(I)	-	Y component of velocity in ft/sec for vehicle I
61-72	E12.5	VZ(I)	-	Z component of velocity in ft/sec for vehicle I
				(There will be one card number 4 for each vehicle entered in the vehicle array.)

Column	Format	Symbol	Input	Comments
CARD 5				
1-3	I3	Num(1)	-	Any integer between 1 and 100 of the readers choice is to be entered (right justified)
4-6	I3	Num(2)	-	see above
7-9	I3	Num(3)	-	" "
10-12	I3	Num(4)	-	" "
13-15	I3	Num(5)	-	" "
16-18	I3	Num(6)	-	" "
19-21	I3	Num(7)	-	" "
22-24	I3	Num(8)	-	" "
25-27	I3	Num(9)	-	" "
28-30	I3	Num(10)	-	" "
CARD 6				
1-12	E12.5	VGAMA	-	Vulnerability level for gamma rays (total gamma fluence)
13-24	E12.5	VXRAY	-	Vulnerability level for x-rays in cal/cm^2
25-36	E12.5	VTHERM	-	Vulnerability level for thermal energy in cal/cm^2
37-48	E12.5	VBLAST1	-	Vulnerability level for overpressure in psi
49-60	E12.5	VNEUT	-	Vulnerability level for neutrons (total neutron fluence)

Column	Format	Symbol	Input	Comments
CARD 6				
61-72	E12.5	VQ	-	Vulnerability level for dynamic pressure in psi (Entry of a zero will cause the associated effect to be deleted from the analysis.)

Note: The appropriate sequence of cards 7, 8, 9, 10 must be repeated for each burst that is to be treated in the program.

Column	Format	Symbol	Input	Comments
CARD 7				
1-12	E12.5	TIMEX	-	Incremental time in sec at which a burst occurs. (Time begins at time equal zero and TIMEX may have any value including zero. Bursts separated by a zero time increment are treated as separate bursts.)
13-24	E12.5	W	-	Weapon yield in KT
25-36	E12.5	HG	-	Height of ground in ft. above sea level
37-38	I2	OPT1	0	Option for user to enter the coordinate position of burst (right justified)
		OPT1	1	Option for automatic placement of the burst (right justified)
39-40	I2	IODAT	0	Option for printout of vehicle losses only (right justified)
		IODAT	1	Option for printout of all effects parameters (right justified)

Column	Format	Symbol	Input	Comments
CARD 7				
41-42	I2	OPT2	0	Option to allow change in velocity vector (allowed only if OPT1 = 0)
		OPT2	1	Option to retain original velocity vectors
CARD 8 (required only if OPT1 = 0)				
1-12	E12.5	BURSTX	-	X coordinate position in feet for burst
13-24	E12.5	BURSTY	-	Y coordinate position in feet for burst
25-36	E12.5	BURSTZ	-	Z coordinate position in feet for burst
				(Coordinates relative to the common sea level origin of coordinates described above.)
CARD 9 (required only if OPT1 = 0 and OPT2 = 0)(multiple card)				
1-12	E12.5	VX(I)	-	New X component of velocity for vehicle I (ft/sec)
13-24	E12.5	VY(I)	-	Y component of velocity for vehicle I (ft/sec)
25-36	E12.5	VZ(I)	-	Z component of velocity for vehicle I (ft/sec)
				(There will be one card 9 entered for each vehicle in the original vehicle array.)
CARD 10 (required if OPT1 = 1)				
1-12	E12.5	spe	-	Spherical probable error radius in feet

Appendix D

CSSANE Program Source Listing

```
      PROGRAM GUIDE (INPUT,OUTPUT)
C ***********************************************************************
C FLOW OF ANALYSIS IS CCNTROLLED BY PROGRAM GUIDE.
C SUBROUTINES CALLED BY GUIDE ARE TARGET,GAMA,XRAY,THERM,BLAST1,AND NEUT
C ***********************************************************************
      COMMON/CAPRI/DISPR(100),PCSZ(100),KTEMP, TEMPS,TM(3),VEHIC(100),II
     1          ,VBLAST1,VQ,ICDAT
      COMMON/GRND/HZ,HG,HR,W
      COMMON/POS/P,BURSTX,BURSTY,BURSTZ
      COMMON/INFO/POSX(100),POSY(100),VX(100),VY(100),VZ(100)
      COMMON/BIT/ PO,VIS,RHO,ZH
      DIMENSION NUM(10)
      INTEGER COUNT,CYCLE,OPT1,CPT2
C ENTER VISIB. LEVEL, H2O VAPOR PRES., ALBEDO, HAZE LEVEL
C ENTER NUMBER OF VEHICLES AND NUMBER OF BURSTS
C ENTER TEMPERATURE VALUES IF NCN-STANDARD ATMOSPHERE DESIRED
C (ENTER ZEROES FOR STD. ATMOS.)
      READ 22,VIS,PO,RHO,ZH
      READ 21,II,CYCLE
      READ 40,KTEMP,TEMPS,TM
      COUNT=0.
      DO 100 I=1,II
      VEHIC(I)=1
  100 READ 22,POSX(I),PCSY(I),PCSZ(I),VX(I),VY(I),VZ(I)
      READ 21,(NUM(I),I=1,10)
      PRINT 25
      PRINT 26
      DO 101 I=1,II
  101 PRINT 27,I,POSX(I),POSY(I),POSZ(I),VX(I),VY(I),VZ(I)
      PRINT 82
      PRINT 84,CYCLE
      PRINT 86,VIS
      PRINT 88,RHO
      PRINT 90,PO
      IF (KTEMP.EQ.0) GO TO 102
      PRINT 92
      PRINT 96
      PRINT 97
      PRINT 94,TEMPS,TM(1),TM(2),TM(3)
  102 PRINT 98
C
C ENTER VULNERABILITY LEVELS FOR TYPE VEHICLE
C ENTER ZERO FOR EFFECTS TO BE DELETED
      READ 22,VGAMA,VXRAY,VTHERM,VBLAST1,VNEUT,VQ
C STATEMENT 104 BEGINS LOOP THAT CYCLES ONCE FOR EACH BURST
C
  104 READ 24,TIMEX,W,HG,OPT1,IODAT,OPT2
      R=0
      COUNT=COUNT+1.
```

```
C NEXT 10 LINES UPDATE VEHICLE POSITIONS TO TIME OF BURST
C TIMEX IS INCREMENTAL TIME
C
  105 PRINT 10,COUNT
      PRINT 26
      AA=0.
      DO 109 I=1,II
      IF(VEHIC(I))107,109
  107 POSX(I)=POSX(I)+VX(I)*TIMEX
      POSY(I)=POSY(I)+VY(I)*TIMEX
      POSZ(I)=POSZ(I)+VZ(I)*TIMEX
      AA=AA+1.
      PRINT 27,I,POSX(I),POSY(I),POSZ(I),VX(I),VY(I),VZ(I)
      IF (POSZ(I).GE.HG) GO TO 109
      VEHIC(I)=.
      PRINT 32,I
  109 CONTINUE
      IF(AA.EQ.0)  GO TO 311
  110 RFB=110*(W**.4)
      IF (OPT1) 305,300
C
C BRANCH 300 FOR USER PLACEMENT OF BURST
C
  300 READ 22,BURSTX,BURSTY,BURSTZ
      IF (OPT2.EQ.1) GO TO 303
      DO 302 I=1,II
  302 READ 22,VX(I),VY(I),VZ(I)
  303 PRINT 70
      PRINT 78,BURSTX,BURSTY,BURSTZ
      PRINT 79,HG
      PRINT 80,TIMEX
      GO TO 330
C
C BRANCH 305, SUBROUTINE TARGET PLACES BURST ACCORDING TO A SPHERICALLY
C NORMAL DISTRIBUTION
C DIRECT ATTACK ON FIRST OCCUPIED SLOT IN VEHICLE ARRAY
C
  305 READ 22,SPE
      DO 310 I=1,II
      IF(VEHIC(I))306,310
  306 TARGX=POSX(I)
      TARGY=POSY(I)
      TARGZ=POSZ(I)
      GO TO 315
  310 CONTINUE
  311 PRINT 35
      GO TO 900
C IRC USED TO PRECYCLE THE RANDOM NUMBER GENERATOR IN TARGET
C
  315 IRC=NUM(COUNT)
      IF (SPE.LT.100) GO TO 322
      PRINT 72
      PRINT 73,I
      PRINT 79,HG
```

```
      PRINT 80,TIMEX
      CALL TARGET(SPE,TARGX,TARGY,TARGZ,IRC)
      GO TO 323
C FOR SPE LESS THAN 100, PLACE BURST ON VEHICLE POSITITION
  322 BURSTX=TARGX
      BURSTY=TARGY
      BURSTZ=TARGZ
      PRINT 76
  323 PRINT 74,P,BURSTX,BURSTY,BURSTZ
  330 PRINT 28
      PRINT 29,CCUNT,W
      PRINT 28
      HB=BURSTZ
C FIND SLANT RANGE TO EACH VEHICLE REMAINING AND CHECK FOR FIREBALL
C INTERSECTION  (NEXT 10 LINES)
      DO 350 I=1,IT
      IF(VEHIC(I)) 340,350
 340  DISPX=(POSX(I)-BURSTX)**2
      DISPY=(POSY(I)-BURSTY)**2
      DISPZ=(POSZ(I)-BURSTZ)**2
      DISPR(I)=SQRT(DISPX+DISPY+DISPZ)
      IF(DISPR(I).GT.RFB) GO TO 350
      VEHIC(I)=0
      PRINT 30,I,RFB
  350 CONTINUE
C
C COMPUTE EFFECTS LEVELS AND DETERMINE LOSSES, (NEXT 10 LINES)
C
  112 IF(VGAMA)115,120
  115 CALL GAMA(II,BURSTX,BURSTY,BURSTZ,POSX,POSY,POSZ,VGAMA,VEHIC)
  120 IF(VXRAY)125,130
  125 CALL XRAY
  130 IF(VTHERM)135,140
  135 CALL THERM (VTHERM,RFB)
  140 IF(VBLAST1.EQ.0..AND.VO.EQ.0.) GO TO 170
  145 CALL BLAST1
  170 IF(VNEUT)175,190
  175 CALL NEUT
C
C LOSSES EACH EFFECT PRINTED IN SUBROUTINE
C
  190 CONTINUE
      IF(CYCLE-CCUNT)900,200,104
C
C DETERMINE AND PRINT ALL VEHICLES LOST IN ENTIRE MISSION PHASE
C
  200 PRINT 60
      DO 206 I=1,II
      IF (VEHIC(I))900,205,206
  205 PRINT 62,I
  206 CONTINUE
  900 STOP
   10 FORMAT (1H1,10X,*------VEHICLE POSITIONS AT TIME OF BURST NUMBER*,
     1I3,*------*,//)
```

```
 21 FORMAT (10I3)
 22 FORMAT(7E12.5)
 24 FORMAT (3E12.5,3I2)
 25 FORMAT(1H1,25X,39H-------VEHICLE INITIAL CONDITIONS------//)
 26 FORMAT(8H VEHICLE,12X,15HPOSITION(X,Y,Z),*(FT)*,11X,27HVELOCITY(X,
   1Y,Z)   (FT/SEC)   )
 27 FORMAT(3X,I3,6X,3F10.2,3X,3F10.2)
 28 FORMAT (/,1X, 47(1H*),/,1X,47(1H*))
 29 FORMAT (/7X,* LOSSES FROM BURST NUMBER*,I3,2X,*(*,F7.1,*KT)*)
 30 FORMAT (//,10X,*VEHICLE NUMBER*,I3,* IS INSIDE THE FIREBALL RADIUS
   1*,F5..,* FEET,*,/10X,* AND HAS BEEN REMOVED FROM FURTHER CONSIDERA
   2TION.*,//)
 32 FORMAT (//,10X,*----VEHICLE NUMBER*,I3,* HAS INTERCEPTED *,/,
   114X,*GROUND LEVEL AND HAS BEEN REMOVED.*)
35  FORMAT (/,1X,*ALL VEHICLE SLOTS ARE EMPTY, PROGRAM IS TERMINATED.*
   1)
 40 FORMAT (I1,4F6.0)
 60 FORMAT (//,40H VEHICLES LOST OVER ENTIRE MISSION PHASE)
 62 FORMAT(12X,I3)
 70 FORMAT (/////,1X,134(1H-),/,1X,134(1H-),/,1X,134(1H-),/,*------WEA
   1PON BURST POSITIONED BY USER-----*)
 72 FORMAT (/////,1X,134(1H-),/,1X,134(1H-),/,1X,134(1H-),/,*------WEA
   1PON BURST POSITIONED BY SUBROUTINE TARGET-----*)
 73 FORMAT(10X,*THE TARGET VEHICLE IS VEHICLE #*,I3)
 74 FORMAT( 8X,*BURST DETONATION AT*,F10.3,*FT FROM TARGET VEHICLE*
   1  ,/, 8X,*NUCLEAR DETONATION COORDINATES ARE*,3F10.1,/)
 76 FORMAT( 8X,*--THE SPE IS LESS THAN 100 FEET, BURST HAS BEEN PLACED
   1 AT THE TARGET COORDINATES.--*)
 78 FORMAT( 8X,*NUCLEAR DETONATION COORDINATES ARE*,F10.1,*,*,F10.1,*,
   1*,F10.1)
 79 FORMAT (8X,*GROUND HEIGHT ABOVE SEA LEVEL=*,4X,F8.1,* FT*)
 80 FORMAT (8X,*INCREMENTAL TIME OF BURST=*,8X,F8.1,* SEC*)
 82 FORMAT (///8X,*INPUT PARAMETERS--*)
 84 FORMAT(10X,*NUMBER OF BURSTS ENTERED IS*,9X,I3)
 86 FORMAT(10X,*VISIBILITY AT SEA LEVEL(MI.) IS*,3X,F8.2)
 88 FORMAT(10X,*ALBEDO (GROUND REFLECTANCE) IS*,4X,F8.2)
 90 FORMAT(10X,*H2O VAPOR PRESSURE(SEA LEVEL,MMHG)*,F8.2)
 92 FORMAT(10X,*NONSTANDARD ATMOSPHERE ENTERED*)
 96 FORMAT(10X,*TEMPERATURES IN DEGREES RANKINE--*)
 97 FORMAT (/,10X,*AT SEA LEVEL*,3X,*AT RECEIVER*,3X,*AT GROUND*,3X,*A
   1T BURST*)
 94 FORMAT (10X,4(2X, F10.1))
 98 FORMAT (10X,*STANDARD ATMOSPHERE SPECIFIED*)
    END
```

```
      SUBROUTINE TARGET (SPE,X,Y,Z,IPC  )
C *****************************************************************************
C SUBROUTINE TARGET POSITIONS THE BURST ACCORDING TO A NORMAL DISTRIBU-
C TION OF ERROR
C CALLING ROUTINE IS GUIDE
C *****************************************************************************
      COMMON/POS/R,BURSTX,BURSTY,BURSTZ
      SUMX=0.
      SUMY=0.
      SUMZ=0.
C XYZ IS VEHICLE COORDINATE POINT ON WHICH BURST IS TARGETED
      SIGMA=SPE/1.538
      DO 10 I=1,IPC
   10 X1=RANF(DUM)
      DO 20 I=1,36
      X2=RANF(DUM)
      IF(I.GT.12) GO TO 14
      SUMX=SUMX+X2
      GO TO 20
   14 IF(I.GT.24) GO TO 16
      SUMY=SUMY+X2
      GO TO 20
   16 SUMZ=SUMZ+X2
   20 CONTINUE
      RX=((SUMX-6.)*SIGMA)**2
      RY=((SUMY-6.)*SIGMA)**2
      RZ=((SUMZ-6.)*SIGMA)**2
      R=RX+RY+RZ
      RX1=SQRT(R-RY-RZ)
      RY1=SQRT(R-RX-RZ)
      RZ1=SQRT(R-RX-RY)
      R=SQRT(R)
      BURSTX=X+RX1
      BURSTY=Y+RY1
      BURSTZ=Z+RZ1
      END
```

```
      SUBROUTINE BLAST1
C ****************************************************************************
C SUBROUTINE BLAST1 COMPUTES THE BLAST EFFECTS PARAMETERS AND  MAKES
C SURVIVAL TESTS
C
C CALLING ROUTINE IS GUIDE
C BLAST1 CALLS SUBROUTINES TRIPNT,MOTION,SETUP,MACURE, AND ATMOS
C ****************************************************************************
      COMMON/CARRI/DISPR(100),PCSZ(100),KTEMP, TEMPS,TM(3),VEHIC(10 ),I
     1           ,VBLAST1,V0,ICDAT
      COMMON/GRND/HZ,HG,HP,W
      COMMON/BIN/POSX1,POSY1
      COMMON/TRI/PZ,PG,PB,       PZR,PGR,PBR,  SR,FR,SRE,ALP1ER,ALP1E,
     1          R90,PBPZ,R,PBRW,INCOMP
      COMMON/SENSE/CFS
      COMMON/COLD/CF11(2),CF22(2),CF33(2),CF44(2),CF55(2),CFR(6),CF1(7)
     1           CF2(7),CF3(7)
      COMMON/TAB/ TAB1I(69),TAB1D(69),TAB2I(62),TAB2D(62),TAB3I(69),
     1           TAB3D(69),TAB4I(18),TAB4D(18),TAB5I(26),TAB5D(26),
     2           TAB6I(69),TAB6D(69)
      COMMON/CON/UL2(7),UL3(8),UL4(8),UL5(5),
     1          C4(7),C5(7),C6(7),C7(8),C8(8),C9(8),C10(8),C11(8),
     2          C12(8),P2(8),P3(8),A1E(41),ACF(13),CF(13)
      COMMON/PNT/RA,STC,PHIR,SHE,ST,XKK,ALTSRG,HT,XKKX
      COMMON/OVP/DELP,DELPD,DELPR,CONT,NIT,XITER
      COMMON/TBLKUP/L1,LF,NA(6),XL(100),NNEX
      DIMENSION P(3),H(3),PR(3),TEMP(3),RHO(3),SS(3)
      EQUIVALENCE (P,PZ),(H,HZ),(PR,PZR),(RHOZ,RHO(1)),(RHOG,RHO(2)),
     1           (RHOB,RHO(3)),(SSZ,SS(1)),(SSG,SS(2)),(SSB,SS(3))
      DATA CF11/.599829717,.5999J265538/
      DATA CF22/-.813121060,-.33454567092/
      DATA CF33/.0537959684,.20153883184/
      DATA CF44/.178612593,-.042235077752/
      DATA CF55/.137932981,.0138268822887/
      DATA CFS/1.85/
      DATA CFR/.5,.8,1.2,1.6,3.6,10./
      DATA CF1/0.,-.6444,-.1625,-.05,-.007,.0001111,0./
      DATA CF2/.6499,1.2943,.4725,.2.53,.0424,-.003466,0./
      DATA CF3/.107076,-.154024,.195,.354,.50408,.57704,.591/
      R90=90.0/57.296
      DO 10 J=1,18
      TAB4I(J)=TAB4I(J)/57.296
10    TAB4D(J)=TAB4D(J)/57.296
      NN=70
      DO 20 J=1,69
      N=NN-J
      TAB3I(J)=TAB1D(N)
20    TAB3D(J)=TAB1I(N)
      WOR=W
      PRINT 1555
      N=1
   30 IF(VEHIC(N)) 34,32
   32 N=N+1
      IF(N.GT.IT) GO TO 1130
      GO TO 30
```

```
   34 SR=DISPR(N)
      HZ=POSZ(N)
      PSL=2116.217/144.
      NIT=0
      XITER=0.
      XKKX=0.
      CONT=0.
      DELPD=0.
      INCOMP=1
      SPE=0.0
      ALP1E=0.0
      STO=0.0
      RA=0.0
      ST=0.0
      HT=0.0
      TSA=0.0
      KCASE=0
      DELP=0
      SRSV=SR
 120  IF (HB.LT.250000.) GO TO 130
      CALL SETUP (ACF,1,2,13,0,0,0,0,0)
      CALL MACURE (CF,HB,0,0,0,0,0,LER,CFF)
      W=CFF*WOR
  130 KCASE=KCASE+1
 210  IF (HB.LT.250000.) GO TO 220
      PRINT 1280
      PRINT 1290,    HB
      GO TO 1130
 220  ALTM=ABS(HZ-HB)
      IF (SRSV-ALTM) 240,250,250
 240  PRINT 1400,    HB,HZ,SR
      GO TO 1060
  250 HZ1=1.
      HZSAV=HZ
      INTC=0
      FLAG=0.
      SFR=0.
      DT=.1
      TT=.0
      SR=SR/1000.
      GO TO 270
  260 IF(HZ.EQ.HZ1) GO TO 490
      HZ=HZ1
  270 DO 290 J=1,3
      CALL ATMOS (H(J),TEMP(J),DEN,RHO(J),TR,PR(J),SS(J),VC,KER)
      IF (KER.NE.1) GO TO 300
 290  P(J)=PR(J)*PSL
      GO TO 350
 300  PRINT 1270,    J,KER
      GO TO 1060
 350  IF (KTEMP.EQ.0) GO TO 430
      PSL=14.696*TEMPS/518.67
 360  DO 370 J=1,3
      P(J)=P(J)*TEMP(J)/TM(J)
      PR(J)=P(J)/PSL
```

```
      RHO(J)=RHO(J)*TM(J)/TEMP(J)
370   SS(J)=49.02*TM(J)**.5
  430 PBPZ=PZ/PB
      SSZR=SSZ/1116.4437
      PBRW=(PBR/W)**.333333
      PZRW=(PZR/W)**.333333
 440  IF (SR.NE.0.0) GO TO 490
      PRINT 1160
      GO TO 1060
490   CALL TRIPNT (KCASE)
      IF (INCOMP.EQ.1) GO TO 1060
550   PBRWFR=(PBR/(W*FR))**.333333
      PZRWFR=(PZR/(W*FR))**.333333
      RBAR=SR*PBRWFR
      CALL SETUP (TAB1I,1,2,69,0,0,0,0,0)
      CALL MACURE (TAB10,RBAR,0,0,0,0,0,LER,SDELP)
      IF (HZ.NE.HP) GO TO 560
      DELP=SDELP*PBR
      ALFA=1.0
      GO TO 570
560   CALL SETUP (TAB2I,1,2,62,0.0,0,0,0)
      CALL MACURE (TAB20,RBAR,0,0,0,0,0,LER,ALFA)
      DELP=SDELP*PBR*PBPZ**ALFA
570   EPSILO=DELP/PZ
      SFV=SSZ*(1.0+6.0*EPSILO/7.0)**.5
      Q=2.5*DELP**2.0/(7.0*PZ+DELP)
      CALL SETUP (TAB6I,1,2,69,0,0,0,0,0)
      CALL MACURE (TAB60,RBAR,0,0,0,0,0,LER,TSACAP)
      TSA=TSACAP/(SSZR*PZRWFR)
      CALL MOTION(N,SFV,SR,HZ1,DT,SFR,FLAG,SEPD,TT,HZSAV,SEPDT,INTC)
      IF (INTC.EQ.1) GO TO 571
      VEHIC(N)=0
      PRINT 1560,N
      GO TO 1070
  571 SR=SR/1000.
      IF(FLAG.LT.3.) GO TO 572
      IF(SEPDT.LT.0.) GO TO 574
      PRINT 1490,N
      GO TO 1070
  572 IF(ABS(SEPD).GT.200.) GO TO 260
  574 DO 580 J=1,7
      IF (RBAR.LT.UL2(J)) GO TO 590
580   CONTINUE
      TDPZ=.252609+(1.0/11.21)*ALOG(RBAR)
      GO TO 600
590   TDPZ=C4(J)*RBAR**2+C5(J)*RBAR+C6(J)
600   DO 610 J=1,8
      IF (RBAR.LT.UL3(J)) GO TO 620
610   CONTINUE
      J=8
620   TMV=C7(J)*RBAR**P2(J)+C8(J)*RBAR+C9(J)
      DO 630 J=1,8
      IF (RBAR.LT.UL4(J)) GO TO 640
630   CONTINUE
      J=8
```

```
640   TDRZ=C10(J)*RBAR**P3(J)+C11(J)*RBAR+C12(J)
      PDOOP=TDPZ/(SSZR*PZPWFP)
      PMV=5.0*EPSILO*SSZ/(7.0*(1.0+6.0*EPSILO/7.0)**.5)
      PDMV=TMV*PDOOP
      POD=RHOZ*(7.0+6.0*EPSILO)/(7.+EPSILO)
      PDOD=TDPZ*PDOOP
      SP=SP*1000.
      IF(VBLAST1.EQ.0.) GO TO 660
      IF(VBLAST1.GT.DELP) GO TO 660
      VEHIC(N)=0.
      PRINT 1500,N,DELP,VBLAST1
      GO TO 680
  660 IF(VQ.EQ.0.) GO TO 680
      IF (VQ.GT.Q) GO TO 680
      VEHIC(N)=0.
      PRINT 1550,N,Q,VQ
  680 IF (IODAT.EQ.0) GO TO 1060
  730 PRINT 1430,N
      PRINT 1440,POSX1,POSY1,HZ1
      PRINT 1450,HZ,SR,TSA,SFV,Q,DELP,PMV,POD,PDOD
      PRINT 1460,PDOOP,PDMV
      IF (HB.LT.25000.) GO TO 740
      GO TO 1060
  740 PRINT 1320
1060  CONTINUE
 1070 N=N+1
      IF(N.LE.II) GO TO 30
 1130 CONTINUE
1160  FORMAT (1H ,////,10X,80HSLANT RANGE FOUND EQUAL TO ZERO IN OVERPRE
     1SSURE SOLUTION PROCEEDING TO NEXT CASE)
1270  FORMAT (1H0,8HATMOS ER,I2,2H =,I3)
1280  FORMAT (1H0,///,48X,37HBLAST EFFECTS ARE ESSENTIALLY REDUCED,//,45
     1X,24HTO ZERO AT THIS ALTITUDE)
1290  FORMAT (1H0,47X,5HHB = ,1PE12.5)
1320  FORMAT (1H0,22X,39HYIELD CORRECTION FACTOR IS EQUAL TO ONE)
1430  FORMAT(/////45X,40(1H*),///45X,40H*    AN OVERPRESSURE SOLUTION CA
     1NNOT   *,/,45X,40H*    BE OBTAINED WITH THE GIVEN         *,/,45X,(
     20H*    INPUT GEOMETRY                       *,//,60X,4HHB =,E12.5,/,(
     30X,4HHZ =,E12.5,/,60X,4HSR =,E12.5,//,45X,40H*    THE PROGRAM WILL
     4 PROCEED WITH      *,/,45X,40H*    THE NEXT CASE
     5  *,///45X,40(1H*))
 1430 FORMAT(//,5X,*SHOCK FRONT PARAMETERS AT INTERCEPT OF VEHICLE NUMB
     1R*,I3)
 1440 FORMAT (5X,*VEHICLE POSITION AT SHOCK INTERCEPT(X,Y,Z)*,2X,3F10.3
     1//)
 1450 FORMAT(1H0,10X,50HRECEIVER HEIGHT AT SHOCK INTERCEPT (FT)
     1  ,F10.4,//,10X,50HSLANT RANGE AT SHOCK INTERCEPT (FT)
     2   ,F10.4,//,10X,50HTIME OF SHOCK ARRIVAL (SEC)
     3    ,F10.4,//,10X,50HSHOCK FRONT VELOCITY (FT/SEC)
     4     ,F10.4,//,10X,50HPEAK DYNAMIC PRESSURE (PSI)
     5      ,F10.4,//,10X,50HPEAK OVERPRESSURE (PSI)
     6       ,F10.4,//,10X,50HPEAK MATERIAL VELOCITY (FT/SEC)
     7        ,F10.4,//,10X,50HPEAK OVERDENSITY (SLUGS/FT**3)
     8         ,F10.4,//,10X,50HPOSITIVE DURATION OF OVERDENSITY (SEC)
     9          ,F10.4)
```

```
1460 FORMAT (1H0,3X,50HPOSITIVE DURATION OVERPRESSURE (SEC)
    1  ,F10.4,//,10X,50HPOSITIVE DURATION MATERIAL VELOCITY (SEC)
    2   ,F10.4,/)
1490 FORMAT(10X,*----VEHICLE NUMBER*,I3,* IS OUTRUNNING SHOCK FRONT.*)
1510 FORMAT(10X,*----VEHICLE NUMBER*,I3,* HAS BEEN SUBJECTED TO AN OVER
    1PRESSURE OF*,/14X,F10.4,* AND HAS BEEN REMOVED FROM THE PROGRAM.*,
    2/,10X,*----THE OVERPRESSURE VULNERABILITY LEVEL IS*,F10.4)
1550 FORMAT(10X,*----VEHICLE NUMBER*,I3,* HAS BEEN SUBJECTED TO A DYNAM
    1IC PRESSURE OF*,/,F10.4,* AND HAS BEEN REMOVED FROM THE PROGRAM.*,
    2/,10X,*----THE DYNAMIC VULNERABILITY LEVEL IS*,F10.4)
1555 FORMAT (///,1X,*RESULTS FROM BLAST EFFECTS COMPUTATIONS*)
1560 FORMAT (//,10X,*----VEHICLE NUMBER*,I3,* HAS INTERCEPTED *,/,
    114X,*GROUND LEVEL AND HAS BEEN REMOVED.*)
     END
```

```
      SUBROUTINE THERM (VTHERM,RFB)
C ************************************************************************
C SUBROUTINE THERM COMPUTES THERMAL ENERGY LEVELS FOR EACH VEHICLE AND
C MAKES A SURVIVIVALBEITY DETERMINATION.
C
C THERM IS CALLED BY ROUTINE BLAST1
C SUBROUTINES CALLED BY THERM ARE TRANS,ATMOS,SETUP,MACURE
C ************************************************************************
      COMMON/BIT/ PO,VIS,RHO,ZH
      COMMON/TARTH/ TAW1(12),TBT1(12),TBT2(12),
     1AAA1(22),AAA2(120),BB1(39),BB2(38 ),TEV1(8),TEV2(8)
      COMMON/CAPRI/DISPP(1 . ),PCSZ(1 0),KTEMP, TEMPS,TM(3),VEHIC(100),I
     1              ,VBLAST1,VG,ICDAT
      COMMON/GRND/HZ,HG,HB,W
      COMMON/POS/R,BURSTX,BURSTY,BURSTZ
      COMMON/INFO/POSX(100),POSY(100),VX(100),VY(100),VZ(100)
      CHK=0
      WMT=W/1000
      PRINT 810
      HOB=HB
    3 CALL ATMOS(HOB,TEMP,DEN,RHO,TR,PR,SS,VC,KER)
      IF(KER.NE.1) GO TO 5
      IF(KTEMP.EQ.0) GO TO 7
      DEN=DEN*(TM(3)/TEMP)*(518.67/TEMPS)
      GO TO 7
    5 PRINT 80 ,KER
      GO TO 300
    7 CONTINUE
      TMIN=(6 .*(WMT**.4))/1000.
      TMAX2=.93*(WMT**.42)*(DEN**.42)
C DETERMINE THE THERMAL YIELD (NEXT 13 LINES)
      H=    HB*3.048E-4
      TEFF=EXP((-3.5797123E-1-8.804057E-3*H+7.13 801E-4*H*H-1.25480 E-5
     1H*H*H+6.423205E-8*H*H*H*H)*2.3 2585093)
      IF((1.5*RFB).LT.HB) GO TO 15
C GROUND BURST CONDITION
      WTH=.32*W*1.E12
      PI=2.*3.1416
      CHK=1
      GO TO 20
C
C AIR BURST CONDITION
C
   15 WTH=(TEFF*W**.94)*1.E12
      PI=4.*3.1416
      CHK=2
   20 N=1
C
C 78 BEGINS LOOP TO TEST EACH VEHICLE
C
   78 IF(VEHIC(N))85,80
   80 N=N+1
      IF(N.GT.II) GO TO 300
      GO TO 78
   85 QMHP=0
```

```
      QP=0
C VEHICLE POSITTCN AND SLANT RANGE TO BURST AT TIME OF 2ND MAX.
      PX=POSX(N)+VX(N)*TMAX2
      PY=POSY(N)+VY(N)*TMAX2
      PZ=POSZ(N)+VZ(N)*TMAX2
      DELX=ABS(BURSTX-PX)
      DELZ=BURSTZ-PZ
      DX=(BURSTX-PX)**2
      DY=(BURSTY-PY)**2
      DZ=(BURSTZ-PZ)**2
      DZZ=(PZ-HG)**2
      SRR=SQRT(DX+DY+DZZ)
      SR=SQRT(DX+DY+DZ)
      SRMI=SR/5280
      SRCM=(SR*12*2.54)**2
      IF(HB.GT.50000) GO TO 100
C
C DETERMINE THE REFLECTED THERMAL ENERGY (NEXT 15 LINES)
C
      IF(HB.GT.30000) GO TO 40
      IF(CHK.EQ.2) GO TO 25
      SRN=SR/RFB
      PFE=ACOS((PZ-HG)/SR)
      CALL SETUP (AAA1,1,3,12,10,0,0,0,0 )
      CALL MACURE (AAA2,SRN,PFE,0,0,0,0,LER,GAM)
      GO TO 30
   25 XRO=DELX/(HB-HG)
      HRO=(PZ-HG)/(HB-HG)
      CALL SETUP (BB1,1,3,19,20,0,0,0,0)
      CALL MACURE (BB2,XRO,HRO,0,0,0,0,LER,GAM)
   30 TYPE=1
      CALL TRANS (TYPE,PZ,SR,SRR,CHK,TR)
C REFLECTED THERMAL FLUENCE IN CAL/CM2 FOR AIR OR GRND. BURST
      SRRCM= (SRR*12.*2.54)**2
      QR=(WTH*TR*RHO*GAM)/(PI*SRRCM)
   40 TYPE =2
      CALL TRANS (TYPE,PZ,SR,SRR,CHK,TD)
      QDFF=(WTH*TD)/(PI*SRCM)
      QDFFUN=WTH/(PI*SRCM)
C DIRECT FLUENCE (CAL/CM2) NORMALLY INCIDENT ON HORIZONTAL RECEIVER
      QDN=QDFF*(ABS(PZ-HB)/SR)
      IF(PZ.GT.100000) PRINT 865
      IF(DELZ.GT.0) GO TO 50
      QMHR=QR+QDN
      IF(VTHERM.GT.QMHR) GO TO 50
      VEHIC(N)=1
      PRINT 860,N,QMHR,VTHERM
      GO TO 150
   50 IF(VTHERM.GT.QDFF) GO TO 150
      VEHIC(N)= 0
      PRINT 860,N,QDFF,VTHERM
      GO TO 150
C
C COMPUTATIONS FOR HIGH ALTITUDE BURST (HOB>50000 FT)
C
```

```
 100 IF(PZ.LT.50000) GO TO 120
     QDFF=WTH/(PI*SRCM)
     QDFFUN=QDFF
     QDN=QDFF*(ABS(PZ-HB)/SR)
     IF(VTHERM.GT.QDFF) GO TO 150
     VEHIC(N)=0
     PRINT 860,N,QDFF,VTHERM
     GO TO 150
 120 CALL SETUP(TBV1,1,2,8 ,0,0,0,0,0)
     CALL MACURE (TBV2,HOB,0,0,0,0,0,LER,FUV)
     STHET=   HB-PZ)/SR
     SSTH=STHET**2
     R=9987./STHET*(1.-EXP(-4.55E-5*(HB-28000.)))
     IF (PZ.GT.28000) GO TO 130
     R=R+31746./STHET*(EXP(-3.15E-5*PZ)-.414)
 130 QDFF=WTH/(SRCM*(HB-PZ)**2)*(FUV*EXP(-1.31E-4*R)+(1-FUV)*EXP(-1.31E
    1-5*R))*SSTH
     QDFFUN=WTH/(PI*SRCM)
     QDN=QDFF*(HB-PZ)/SR
     IF(VTHERM.GT.QDFF) GO TO 150
     VEHIC(N)=0
     PRINT 860,N,QDFF,VTHERM
 150 IF(IODAT.EQ.0) GO TO 250
     PRINT 870,N
     PRINT 875,QDFFUN
     PRINT 880,HB,SRMI,TMAX2,QDFF,QDN
     IF(HB.GE.30000) GO TO 250
     PRINT 890,QR,QMHR
 250 N=N+1
     IF(N.LE.II) GO TO 78
 300 CONTINUE
 800 FORMAT (10X,*----ATMOS SUBROUTINE ERROR NUMBER*,I3)
 810 FORMAT (1H0,1X,*RESULTS FROM THERMAL EFFECTS COMPUTATIONS*)
 860 FORMAT (1H0,9X,*----VEHICLE NUMBER*,I3,* HAS BEEN SUBJECTED TO THE
    1RMAL FLUENCE OF*,/,14X,F10.4,*(CAL/CM**2) AND HAS BEEN REMOVED FRO
    2M THE PROGRAM*,/,10X,*----THE THERMAL VULNERABILITY LEVEL IS*,F10
    34,* (CAL/CM**2)*)
 865 FORMAT (14X,*(USER WARNING-RECEIVER ABOVE 100 KFT--THERMAL VALUES
    1COMPUTED THIS CASE HAVE BEEN SUBJECTED TO EXCESSIVE ATTENUATION.)
    2)
 870 FORMAT (// ,5X,*THERMAL EFFECTS PARAMETERS FOR VEHICLE NUMBER*,I3
    1//)
 880 FORMAT (1H0,9X,50HHEIGHT OF BURST (FT)
    1   ,F10.4,//,10X,50HSLANT RANGE AT TIME OF PEAK RADIANT POWER (MI.
    2    ,F10.4,//,10X,50HTIME TO PEAK RADIANT POWER (SEC)
    3     ,F10.4,//,10X,50HDIRECT FREE FIELD FLUENCE (CAL/CM2)
    4      ,F10.4,//,10X,50HDIRECT NORMALLY INCIDENT FLUENCE(CAL/CM2)
    5       ,F10.4,/,10X,*(NORMAL TO A PLANE HORIZONTAL RECEIVER)*)
 890 FORMAT (1H0,9X,50HREFLECTED FLUENCE (CAL/CM**2)
    1  ,F10.4,//,10X,50HREFLECTED + DIRECT NORMAL FLUENCE (CAL/CM2)
    2   ,F10.4,/,10X,*(COMPUTED ONLY IF BURST BELOW RECEIVER)*)
 875 FORMAT (1H0,9X,50HUNATTENUATED FLUENCE (CAL/CM2)
    1  ,F10.4)
     END
```

```
      SUBROUTINE TRIPNT (KCASE)
C     ******************************************************************
C     SUBROUTINE TRIPNT CALCULATES LIMITING ANGLE FOR REGULAR REFLECTION
C         AND PREDICTS WHETHER RECEIVER IS IN OR OUT OF THE FUSED SHOCK
C         REGION
C
C     ROUTINE REQUIREMENTS-
C         NUMEROUS PARAMETERS FORM MAIN ROUTINE THROUGH COMMON
C         CALLS SUBROUTINES SETUP AND MACURE
C
C     CALLING SEQUENCE
C             WHERE-
C                    KCASE=1 FOR OVERPRESSURE SOLUTION
C                          2 FOR TRIPLE POINT PATH SOLUTION
C                          3 FOR RANGE SOLUTION
C     ******************************************************************
C         CALL TRIPNT(KCASE)
      COMMON/TRI/PZ,PG,PB,       PZR,PGR,PBR,  SR,FR,SRE,ALP1ER,ALP1E,
     1            R90,PBPZ,R,PBRW,INCOMP
      COMMON/GRND/HZ,HG,HB,W
      COMMON/SENSE/CFS
      COMMON/COLD/CF11(2),CF22(2),CF33(2),CF44(2),CF55(2),CFP(6),CF1(7),
     1             CF2(7),CF3(7)
      COMMON/TAB/ TAB1I(69),TAB1O(69),TAB2I(62),TAB2O(62),TAB3I(69),
     1            TAB3O(69),TAB4I(18),TAB4O(18),TAB5I(26),TAB5O(26),
     2            TAB6I(69),TAB6O(69)
      COMMON/CON/UL2(7),UL3(8),UL4(8),UL5(5),
     1            C4(7),C5(7),C6(7),C7(8),C8(8),C9(8),C10(8),C11(8),
     2            C12(8),P2(3),P3(5),A1E(41),ACF(13),CF(13)
      COMMON/PNT/RA,STO,PHIR,SHB,ST,XKK,ALTSRG,HT,XKKX
      COMMON/OVP/DELP,DELPD,DELPR,CONT,NIT,XITER
      DIMENSION ALPHA(41),IHED1(5,3),ID(28)
      DATA(IHED1(J),J=6,10)/50H            TRIPLE POINT PATH SOLUTION
     1       /
      DATA (ID(J),J=1,28)/2HSR,2HHZ,2HHG,2HHB,1HW,3HTSA,2HFR,3HSEV,
     1     4HDELP,3HPMV,3HPOD,5HSDELP,4HRBAR,1HR,4HALFA,3HSRE,5HALP1E,
     2     3HSTO,2HRA,2HST,2HHT,5HPDOOP,4HPDMV,4HPDOD,1HQ,4HPHOZ,3HSSZ,
     3     3HCFF/
      PGPB=PG/PB
      ALT=(HB-HG)/1000.0
      R=145.0*W**0.4/1000.0
      SHB=ALT*PBRW
      SHBB=ALT/W**.3333
      IF (SHBB.GT.2.5) GO TO 90
      IF (R.LT.ALT) GO TO 1
      FR=1.6
      IF (SR.EQ.0.) GO TO 5
      XK=ABS(HZ-HB)/(SR*1000.0)
      GO TO 6
    5 XK=0
    6 IF((ABS(XK-1.)).LE..002)  XK=1.
      IF (XK.LE.1.0) GO TO 180
      GO TO 150
   10 XI=0.0
      RBAP=ALT*PBRW
```

```
      CALL SETUP (TAB2I,1,2,62,0,0,0,0,0)
      CALL MACURE (TAB2D,RBAR,0,0,0,0,0,LER,ALFA)
      DO 80 J=1,41
      ALFA=0.
      XI=XI+0.025
      IF (XI.GT.1.0) XI=1.0
      DELPG=PG/XI-PG
20    SDELP=DELPG/(PBR*PGPB**ALFA)
      DDELP=-DELPG*ALOG(PGPB)/(PBR*PGPB**ALFA)
      K=1
      IF (SDELP-CFS) 40,30,30
30    K=2
40    PPP=CF11(K)+CF22(K)*ALOG10(SDELP)+CF33(K)*(ALOG10(SDELP)**2)+CF44(
     1K)*(ALOG10(SDELP)**3)+CF55(K)*(ALOG10(SDELP)**4)
      RBAR=10.**PPP
      AA=ALOG10(2.71828)/SDELP
      BB=2.*ALOG10(SDELP)*AA
      CC=3.*(ALOG10(SDELP)**2)*AA
      DD=4.*(ALOG10(SDELP)**3)*AA
      DPDX=CF22(K)*AA+CF33(K)*BB+CF44(K)*CC+CF55(K)*DD
      DRBAR=RBAR*ALOG(10.)*DPDX
      CF4=0.
      DO 50 II=1,6
      IF (RBAR-CFR(II)) 60,50,50
50    CONTINUE
      II=7
      CF4=-.038
60    SMF=(CF1(II)*RBAR+CF2(II))*RBAR+CF3(II)+CF4*ALOG10(RBAR)
      CAPD=2.*CF1(II)*RBAR+CF2(II)+CF4*ALOG10(2.71828)/RBAR
      CAPQ=CAPD*DRBAR*DDELP
      ALFO=ALFA
      ALFA=(SMF-ALFO*CAPQ)/(1.-CAPQ)
      IF (ABS(ALFA-ALFO)-.0 1) 70,70,20
70    ALTSRG=ALT/(RBAR*(W/PBR)**.333333)
      IF (ALTSRG.GT.1.00) GO TO 80
      ALPHA(J)=ACOS(ALTSRG)*57.295
      IF (ALPHA(J).GT.A1E(J)) GO TO 120
80    CONTINUE
90    IF (KCASE.NE.2) GO TO 100
      INCOMP=1
      PRINT 200,(IHED1(J,KCASE),J=1,5)
      PRINT 210
      PRINT 220,HB
      RETURN
100   FR=1.0
      IF (XITER.GT.1..OR.NIT.GT.1) GO TO 110
110   XK=ABS(HZ-HB)/(SR*1000.0)
      IF ((ABS(XK-1.)).LE...02) XK=1.
      IF (XK.LE.1.0) GO TO 180
      GO TO 150
120   IF (J.NE.1) GO TO 130
      ALP1E=A1E(1)
      GO TO 140
130   ALP1E=((A1E(J)-A1E(J-1))*(ALPHA(J-1)-A1E(J-1))/(A1E(J)-A1E(J-1)-
     1PHA(J)+ALPHA(J-1))+A1E(J))
```

```
140   ALP1ER=ALP1E/57.296
      SRE=ALT/COS(ALP1ER)
      IF (KCASE.EQ.2) GO TO 180
      ALPHI=R90
      IF (HZ.EQ.HB) GO TO 170
      XK=ABS(HZ-HB)/(SR*1000.0)
      IF ((ABS(XK-1.)).LE..002) XK=1.
      IF (XK.LE.1.0) GO TO 160
 150  PRINT 240,XK
      PRINT 250,ID(5),W,ID(9),DELP
      PRINT 250,ID(2),HZ,ID(3),HG
      PRINT 250,ID(4),HB,ID(1),SR
      PRINT 260
      DELPD=DELP
      CONT=CONT+1.
      PRINT 270
      XKK=XK
      XKKX=XK
      RETURN
160   XKK=XK
      XK=ASIN(XK)
      IF (HZ.LT.HB) ALPHI=ALPHI-XK
      IF (HZ.GT.HB) ALPHI=ALPHI+XK
170   ALPHIR=ALPHI-ALP1ER
      CALL SETUP (TAB4I,1,2,18,0,0,0,0,0)
      CALL MACURE (TAB4D,ALPHIR,0,0,0,0,0,LER,PHIR)
      RA=SRE*COS(ALP1ER-PHIR)/COS(ALPHI-PHIR)
      RA=ABS(RA)
      FR=1.0
      IF (XKKX.GT.0.) GO TO 190
      IF (RA.GT.SR) GO TO 190
      CALL SETUP (TAB5I,1,2,26,0,0,0,0,0)
      CALL MACURE (TAB5D,SHB,0,0,0,0,0,LER,FR)
      IF (SHB.LT.1.54) GO TO 190
      IF ((SR-RA).LT.0.1) GO TO 190
      FR=2.33-0.025*RBAR
180   XKK=XK
190   RETURN
C
C
C
200    FORMAT (1H1,45X,5A10,///)
210    FORMAT (1H0,///,48X,35HINPUT PARAMETERS ARE NOT COMPATIBLE,//,48X
      134HFOR THE TRIPLE POINT PATH SOLUTION)
220    FORMAT (1H0,47X,5HHB = ,1PE12.5)
240    FORMAT (38H ***ARG OF ASIN (X) OUT OF RANGE.   X=,E16.8,////)
250    FORMAT (1H0,22X,2(4X,A6,1PE12.5))
260    FORMAT (1X,/////)
270    FORMAT (10X,66HTHE INPUT GIVEN IS INCOMPATABLE WITH A POSSIBLE PH
      1SICAL CONDITION,//,10X,39HTWO ALTERNATE SETS OF OUTPUT ARE GIVEN-
      2/,14X,61H1-RECEIVER DIRECTLY ABOVE OR BELOW THE BURST DEPENDING O
      3 THE,/,16X,57HINITIAL ORIENTATION OF RECEIVER WITH RESPECT TO THE
      4BURST,//,14X,64H2-THE ALTITUDE AT WHICH THE DESIRED GUST OR OVERP
      5ESSURE OCCURRS,//,34X,1H*,/,34X,1H*,/,34X,1H*,/,34X,1H*,/,31X,7H*
      6******,/,32X,5H*****,/,33X,3H***,/,34X,1H*)
       END
```

```
      SUBROUTINE TRANS (TYPE,PZ,SR,SRR,CHK,TT)
      COMMON/TABTH/ TBW1(12),TBT1(12),TBT2(12),
     1AAA1(22),AAA2(120),BB1(39),BB2(380),TBV1(8),TBV2(8)
      COMMON/BIT/ PO,VIS,RHO,ZH
      COMMON /GRND/ HZ,HG,HB,W
      ZS=HB
      HL=HG
      E1=EXP(-4.57E-5*ZH)
      E2=EXP(-4.57E-5*PZ)
      E3=EXP(-4.57E-5*ZS)
      E4=EXP(-4.57E-5*HL)
      IF (TYPE.EQ.1) GO TO 800
C COMPUTATIONS FOR DIRECT TRANSMISSION (NEXT 28 LINES)
C NON-COALTITUDE CASE
      CTHETA=(PZ-ZS)/SR
      IF (ABS(CTHETA).LE..001) GO TO 300
      IF(HB.LE.ZH) GO TO 50
      IF (PZ.LE.ZH) GO TO 25
      TH=1.
      TR=EXP(-.085/CTHETA*(E3-E2))
      GO TO 100
   25 TH=EXP(-16.4*SR/(VIS*(ZS-PZ))*(E2-E1))
      TR=EXP(-.0875*SR/(ZS-PZ)*(E1-E3))
      GO TO 100
   50 IF(PZ.LE.ZH) GO TO 75
      TH=EXP(-16.4/(VIS*CTHETA)*(E3-E1))
      TR=EXP(.0875/CTHETA*(E1-E2))
      GO TO 100
   75 TH=EXP(-16.4/(VIS*CTHETA)*(E3-E2))
      TR=1.
  100 XXW=2.3*PO/CTHETA*(10**(-6.1E-5*ZS)-10**(-6.1E-5*PZ))
      GO TO 1000
C COALTITUDE CASE
  300 IF(ZS.LE.ZH) GO TO 325
      TH=1.0
      TR=EXP((-4.E-6)*SR*EXP((-4.57E-5)*ZS))
      GO TO 400
  325 TH=EXP((-7.5E-4)*SR/VIS*EXP((-4.57E-5)*PZ))
      TR=1.
  400 XXW=(3.23E-4)*PO*SR*(10**(-6.1E-5*ZS))
      GO TO 1080
C COMPUTATIONS FOR REFLECTED TRANSMISSION (NEXT 18 LINES)
  800 CTHETA=(PZ-HL)/SRR
      IF(ABS(CTHETA).LE..001) GO TO 950
      IF(HB.LE.ZH) GO TO 850
      IF(PZ.LE.ZH) GO TO 825
      TH=EXP(-16.4/VIS*(E4-E1))*EXP(-16.4/(VIS*CTHETA)*(E4-E1))
      TR=EXP(-.0875*(E1-E3))*EXP(-.0875/CTHETA*(E1-E2))
      GO TO 900
  825 TH=EXP(-16.4/VIS*(E4-E1))*EXP(-16.4/(VIS*CTHETA)*(E4-E2))
      TR=EXP(-.0875*(E1-E3))
      GO TO 900
  850 IF(PZ.LE.ZH) GO TO 875
      TH=EXP(-16.4/VIS*(E4-E3))*EXP(-16.4/(VIS*CTHETA)*(E4-E1))
      TR=EXP(-.0875/CTHETA*(E1-E2))
```

```
      GO TO 900
  875 TH=EXP(-16.4/VIS*(E4-E3))*EXP(-16.4/(VIS*CTHETA)*(E4-E2))
      TR=1.
  900 XXH=2.3*PO*ABS(10**(-6.1E-5*HL)-10**(-6.1E-5*ZS))+2.3*PO/CTHETA*
     1(10**(-6.1E-5*HL)-10**(-6.1F-5*PZ))
      GO TO 1080
  950 TT=0
      RETURN
C FIND TRANSMISSIVITY FOR INFRARED (NEXT 11 LINES)
C
 1080 IF(CHK.EQ.2) GO TO 1090
C GROUND BURST CONDITION (ASSUME 3000 BLACK BODY)
      FV=.1
      FIR=.9
      CALL SETUP (TBW1,1,2,12,0,0,0,0,0)
      CALL MACURE (TBT1,XXW,0,0,0,0,0,LER,TW)
      GO TO 1095
C AIR BURST (ASSUME 6000BB)
 1090 CALL SETUP (TBW1,1,2,12,0,0,0,0,0)
      CALL MACURE (TBT2,XXW,0,0,0,0,0,LER,TW)
      FV=.50
      FIR=.50
C FIND TOTAL TRANSMISSIVITY
 1095 TT=FV*TR*TH+FIR*TW*(.7+.3*TH)
      END
      SUBROUTINE MOTION(N,SFV,SR,HZ1,DT,SFR,FLAG,SEPD,TT,HZSAV,SEPDT,INT
     1C)
      COMMON/POS/R,BURSTX,BURSTY,BURSTZ
      COMMON/GRND/HZ,HG,HR,W
      COMMON/INFO/POSX(100),POSY(100),VX(100),VY(100),VZ(100)
      COMMON/BIN/POSX1,POSY1
      TT=TT+DT
      POSX1=POSX(N)+VX(N)*TT
      POSY1=POSY(N)+VY(N)*TT
      HZ1=HZSAV+VZ(N)*TT
      IF (HZ1.GE.HG) GO TO 100
      INTC=1
  100 SRSAV=SR*1000.
      DX=(POSX1-BURSTX)**2
      DY=(POSY1-BURSTY)**2
      DZ=(HZ1-BURSTZ)**2
      SR=SQRT(DX+DY+DZ)
C FIND RATE AT WHICH SHOCK FRONT IS CLOSING ON VEHICLE IN TIME DT.
      SEPD=SRSAV-SFR
      SFR=SFV*TT
      SEPDT=SR-SFR
      DSEP=ABS(SEPD)-ABS(SEPDT)
      IF(DSEP.GT.0.) GO TO 120
      FLAG=FLAG+1.
  120 IF(SEPDT.GT.0.) GO TO 130
      DT=-DT1/10.
      RETURN
  130 VCLOS=ABS(DSEP)/ABS(DT)
      DT=SEPDT/VCLOS
      DT1=DT
      END
```

```
      BLOCK DATA
C     ******************************************************************
C     BLOCK DATA CONTAINS TABULATED VALUES USED IN THE MAIN PROGRAM
C     AND IN SUBROUTINES TRIPNT,BLAST1, TRANS, AND THERM
C     ******************************************************************
      COMMON/GRND/HZ,HG,HP,W
      COMMON/TABTH/ TBW1(12),TPT1(12),TBT2(12),
     1AAA1(22),AAA2(120),BB1(39),BB2(380),TEV1(8),TEV2(8)
      COMMON/TRI/PZ,PG,PP,       PZR,PGR,PER,  SR,FR,SRE,ALP1ER,ALP1F,
     1           R90,PBPZ,R,PPPW
      COMMON/TAB/ TAB1I(69),TAB1D(69),TAB2I(62),TAB2D(62),TAB3I(69),
     1           TAB3D(69),TAB4I(18),TAB4D(18),TAB5I(26),TAB5D(26),
     2           TAB6I(69),TAB6D(69)
      COMMON/CON/UL2(7),UL3(8),UL4(8),UL5(5),
     1           C4(7),C5(7),C6(7),C7(8),C8(8),C9(8),C10(8),C11(8),
     2           C12(8),P2(8),P3(8),A1E(41),ACF(13),CF(13)
      DATA (TAB1I(J),J=1,69)/
     1  .050, .0625,  .075, .0875,  .100,  .125,  .150,  .175,  .20 ,
     2  .225,  .250,  .275,  .300,  .325,  .350,  .375,  .400,  .45 ,
     3  .500,  .550,  .600,  .650,  .700,  .750,  .800,  .850,  .90 ,
     4  .950, 1.000, 1.105, 1.221, 1.350, 1.492, 1.649, 1.822, 2.014,
     5 2.226, 2.460, 2.718, 3.004, 3.320, 3.669, 4.055, 4.482, 4.953,
     6 5.474, 6.050, 6.686, 7.389, 8.166, 9.025, 9.974,11.023,12.182,
     713.464,14.880,16.445,18.174,20.086,22.198,24.532,27.113,29.964,
     833.115,36.598,40.447,44.701,50.000,100.00/
      DATA (TAB1D(J),J=1,69)/
     111720., 8000., 4240., 2490., 1660.,  900.,  545.,  360.,  246.,
     2  186.,  144.,  1.7.,  88.8,  73.5,  62.7,  54.5,  46.6,  36.4,
     3  29.3,  24.1,  20.2,  17.2,  14.8,  12.9,  11.3,   9.9,   8.8,
     4   7.9,   7.0,   6.2,   5.2,  4.45,  3.83,  3.30,  2.85,  2.48,
     5  2.10,  1.85,  1.62,  1.43,  1.27,  1.12,   .98,   .87,   .77,
     6   .68,   .60,   .53,   .47,   .41,   .36,   .32,   .28,  .252,
     7  .222,  .198,  .174,  .156,  .139,  .124,  .113,  .100,  .091,
     8  .083, .0755,  .069,  .063, .0574, .0333/
      DATA TAB2I/
     1  0.,.1,.2,
     2 .30, .35, .40, .45, .50, .55, .60, .65, .70, .75, .80, .85, .9 ,
     3 .95, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5,
     4 7.0, 7.5, 8.0, 8.5, 9.0, 9.5, 10., 15., 20., 25., 30., 35., 40.,
     5 45., 50., 55., 60., 65., 70., 75., 80., 85., 90., 95.,100.,150.,
     6200.,250.,300.,350.,400.,450.,500./
      DATA TAB2D/
     1  .020,.0625,.125,
     2.1800,.2150,.2460,.2930,.3320,.3650,.3910,.4150,.4350,.4570,.4600,
     3.4800,.4900,.4990,.5060,.5490,.5620,.5660,.5670,.5660,.565.,[illegible]
     4.5620,.5610,.5605,.5590,.5580,.5575,.5570,.5560,.5540,.5535,.5530,
     5.5475,.5420,.5390,.5350,.5330,.5310,.5290,.5275,.5260,.5230,.5220,
     6.5210,.5200,.5190,.5180,.5170,.5160,.5150,.5060,.5020,.4980,.4940,
     7.4920,.4890,.4870,.4840/
      DATA (TAB4I(J),J=1,18),(TAB4D(J),J=1,18)/
     1     0.0,  5.0, 10.0, 15.0, 20.0, 25.0, 30.0, 35.0, 40.0, 45.0,
     2    50.0, 60.0, 70.0, 80.0, 90.0,100.0,110.0,120.0,
     3     0.0,  0.0, 0.25, 0.50,  1.0,  2.0,  3.5,  5.0,  7.0,  9.5,
     4    12.5, 20.0, 28.0, 36.5, 45.3, 54.5, 63.3, 72.0/
      DATA (TAB5I(J),J=1,26),(TAB5D(J),J=1,26)/
```

```
1     0.0,  0.1,  0.2,  0.3,  0.4,  0.5,  0.6,  0.7,  0.8,  0.9,
2     1.0,  1.1,  1.2,  1.3,  1.4,  1.5,  1.6,  1.7,  1.8,  1.9,
3     2.0,  2.1,  2.2,  2.3,  2.4,  2.5,
4    1.58, 1.62, 1.75, 2.02, 2.39, 2.90, 3.53, 4.30, 5.00, 5.46,
5    5.56, 5.33, 4.45, 3.51, 3.88, 2.45, 2.12, 1.86, 1.65, 1.50,
6    1.36, 1.25, 1.16, 1.08, 1.03, 1.00/
 DATA (TAB6I(J),J=1,69)/
1  .050, .0625,  .075, .0875,  .100,  .125,  .150,  .175,  .200,
2  .225,  .250,  .275,  .300,  .325,  .350,  .375,  .400,  .45 ,
3  .500,  .550,  .600,  .650,  .700,  .750,  .800,  .850,  .900,
4  .950, 1.000, 1.105, 1.221, 1.350, 1.492, 1.649, 1.822, 2.014,
5 2.226, 2.460, 2.718, 3.004, 3.320, 3.669, 4.055, 4.482, 4.953,
6 5.474, 6.050, 6.686, 7.389, 8.166, 9.025, 9.974,11.023,12.182,
713.464,14.880,16.445,18.174,20.086,22.198,24.532,27.113,29.964,
833.115,36.598,40.447,44.701,50.000,100.00/
 DATA (TAB6C(J),J=1,69)/
1.00062,.00106,.00176,.00255,.00363,.00638,.00994,.01432,.01954,
2.02555,.03235,.04032,.04903,.05844,.06853,.07924,.09055,.11481,
3.14105,.16905,.19860,.22955,.26173,.29501,.32929,.36445,.40041,
4.43710,.47444,  .555,  .646,  .749,  .864,  .994,  1.14,  1.30,
5  1.48,  1.68,  1.90,  2.15,  2.43,  2.73,  3.07,  3.45,  3.86,
6  4.32,  4.83,  5.40,  6.02,  6.71,  7.47,  8.32,  9.25, 10.29,
7 11.43, 12.69, 14.09, 15.64, 17.34, 19.23, 21.32, 23.62, 26.17,
8 28.99, 32.11, 35.55, 39.36, 44.10, 90.00/
 DATA(UL2(J),J=1,7)/0.0,.35,.45,0.6,1.7,3.8,1.0./,
1     (UL3(J),J=1,9)/.375,.5,1.0,2.5,7.0,10.0,17.0,0.0/,
2     (UL4(J),J=1,8)/.23,0.5,.85,1.12,1.5,4.2,10.0,0.0/,
3     (UL5(J),J=1,5)/.265,.43,1.68,5.867375,0.0/
 DATA                                                 (C4(J),J=1,7)/
1-.724616,-.08,-.02,.416667,-.071254,-.007659,-.001997/
 DATA(C5(J),J=1,7),(C6(J),J=1,7),(C7(J),J=1,8),(C8(J),J=1,8)/
1.080499,-.110,.137,-.220833,.277338,.080934,.029527,
2.167066,.1652,.0724,.145 ,.021749,.171847,.272444,
3.160875,-.606061,1.44,.097778,.008592,0.0,-.000083,76.202,
41.813868,-3.554546,-3.16,-.542223,-.114293,-0.00167,0.0,0.0/
 DATA(C9(J),J=1,8),(C10(J),J=1,8),(C11(J),J=1,8),(C12(J),J=1,8)/
12.0443,3.928788,3.22,1.944445,1.432033,1.064650,1.056289,1.0,
21.153846,-6.2972,-1.57143,-3.05556,.618421,.105667,-.00108276,-3.
3,-.003846,7.98454,3.03571,6.01944,-1.80976,-.0654667,.0224069,0.0,
4.0146514,-1.637971,-.345,-1.80889,2.35119,1.1148,.854207,1.0/
 DATA                   (P2(J),J=1,8),(P3(J),J=1,8)/
1                              5*2.,1.,3.,-3., 7*2.,-2./
 DATA (A1E(J),J=1,41)/
1 40.0,39.6,39.4,39.2,39.0,39.0,39.0,39.0,39.1,39.3,39.5,39.6,39.9,
2 40.0,40.4,40.7,41.0,41.3,41.6,42.0,42.4,42.7,43.0,43.5,44.0,44.5,
3 45.3,46.0,47.0,48.0,49.5,50.8,52.3,54.0,56.0,58.0,60.5,63.5,67.5,
4 74.0,90.0/
 DATA(CF(J),J=1,13)/1.0,.98,.96,.917,.83,.66,.47,.343,.265,
1 .211,.175,.143,0./
 DATA(ACF(J),J=1,13)/25000.,50000.,62500.,75000.,87500.,100000.,
1 112500.,125000.,137500.,150000.,162500.,175000.,250000./
 DATA (TBW1(J),J=1,12) /
10.,10.,20.,30.,40.,50.,60.,80.,100.,120.,140.,150./
 DATA (TBT1(J),J=1,12)/
1.89,.72,.65,.62,.58,.56,.54,.51,.48,.45,.42,.41/
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 DATA (TBT2(J),J=1,12)/
1 .97,.80,.74,.70,.67,.64,.62,.58,.54,.51,.48,.47/
 DATA (AAA1(J),J=1,22)/
1 2.00000E+00, 3.00000E+00, 5.00000E+00, 7.50000E+00, 1.00000E+01,
2 1.50000E+01, 2.00000E+01, 2.50000E+01, 3.00000E+01, 4.00000E+01,
3 5.00000E+01, 1.00000E+02,
4 0.,.17,.35,.52,.70,.87,1.05,1.22,1.40,1.57/
 DATA (AAA2(J),J=1,60) /
1 9.58800E-02, 1.10620E-01, 1.13180E-01, 1.29070E-01, 1.43710E-01,
2 1.56880E-01, 1.63820E-01, 1.59600E-01, 1.39400E-01, 1.15000E-01,
3 1.98000E-01, 1.98570E-01, 1.98370E-01, 1.95520E-01, 1.90490E-01,
4 1.80120E-01, 1.60830E-01, 1.31150E-01, 9.59700E-02, 7.30000E-02,
5 3.07130E-01, 3.00440E-01, 2.81630E-01, 2.55980E-01, 2.24740E-01,
6 1.87740E-01, 1.45610E-01, 1.01420E-01, 6.25000E-02, 4.30000E-02,
7 3.68830E-01, 3.57470E-01, 3.28430E-01, 2.88330E-01, 2.40640E-01,
8 1.88200E-01, 1.34800E-01, 8.48700E-02, 4.59100E-02, 2.80000E-02,
9 4.00930E-01, 3.87260E-01, 3.53020E-01, 3.05000E-01, 2.48740E-01,
  1.87770E-01, 1.28520E-01, 7.62200E-02, 3.75600E-02, 2.10000E-02,
$ 4.33620E-01, 4.17940E-01, 3.78340E-01, 3.21970E-01, 2.55870E-01,
$ 1.87000E-01, 1.21960E-01, 6.73000E-02, 2.91800E-02, 1.40000E-02/
 DATA (AAA2(J),J=61,12 ) /
1 4.50130E-01, 4.33610E-01, 3.91250E-01, 3.30760E-01, 2.59620E-01,
2 1.86370E-01, 1.18480E-01, 6.27400E-02, 2.49800E-02, 1.10000E-02,
3 4.60080E-01, 4.43090E-01, 3.99060E-01, 3.35770E-01, 2.61970E-01,
4 1.85990E-01, 1.16360E-01, 5.99800E-02, 2.24200E-02, 8.00000E-03,
5 4.66720E-01, 4.49450E-01, 4.04370E-01, 3.39300E-01, 2.63340E-01,
6 1.85720E-01, 1.14940E-01, 5.81200E-02, 2.07300E-02, 7.00000E-03,
7 4.75100E-01, 4.57510E-01, 4.10960E-01, 3.43360E-01, 2.65210E-01,
8 1.85340E-01, 1.13120E-01, 5.57800E-02, 1.86100E-02, 5.00000E-03,
9 4.80090E-01, 4.62320E-01, 4.14930E-01, 3.46290E-01, 2.66320E-01,
$ 1.85120E-01, 1.12030E-01, 5.43600E-02, 1.73200E-02, 4.00000E-03,
$ 4.90010E-01, 4.71930E-01, 4.22860E-01, 3.51510E-01, 2.68490E-01,
$ 1.84560E-01, 1.09830E-01, 5.15400E-02, 1.47600E-02, 2.00000E-03/
 DATA (BB1(J),J=1,39) /
1 0.         , 1.00000E+00, 2.00000E+00, 3.00000E+00, 4.00000E+00,
2 5.00000E+00, 6.00000E+00, 8.00000E+00, 1.00000E+01, 1.20000E+01,
3 1.40000E+01, 1.60000E+01, 1.80000E+01, 2.00000E+01, 2.20000E+01,
4 2.60000E+01, 3.00000E+01, 3.50000E+01, 4.00000E+01,
5 0.         , 2.50000E-01, 5.00000E-01, 7.50000E-01, 1.00000E+00,
6 1.50000E+00, 2.00000E+00, 3.00000E+00, 4.00000E+00, 6.00000E+00,
7 8.00000E+00, 1.00000E+01, 1.20000E+01, 1.40000E+01, 1.80000E+01,
8 2.20000E+01, 2.60000E+01, 3.00000E+01, 3.50000E+01, 4.00000E+01/
 DATA (BB2(J),J=1,95)/
1 1.00000E+00, 4.94300E-01, 1.64300E-01, 4.29000E-02, 1.00000E-03,
2 6.71000E-02, 1.99000E-01, 4.53400E-01, 6.67000E-01, 9.72000E-01,
3 1.16700E+00, 1.31000E+00, 1.41000E+00, 1.48500E+00, 1.59400E+00,
4 1.66900E+00, 1.72200E+00, 1.76400E+00, 1.81000E+00, 1.83500E+00,
5 7.07000E-01, 5.37500E-01, 4.19600E-01, 3.03400E-01, 2.69300E-01,
6 2.60900E-01, 3.11000E-01, 5.03400E-01, 6.86100E-01, 9.79000E-01,
7 1.16000E+00, 1.30000E+00, 1.40000E+00, 1.48000E+00, 1.59200E+00,
8 1.66800E+00, 1.72000E+00, 1.76200E+00, 1.80600E+00, 1.83200E+00,
9 4.47000E-01, 4.31400E-01, 4.36800E-01, 4.32000E-01, 4.37200E-01,
$ 4.48000E-01, 4.72400E-01, 4.57100E-01, 7.20600E-01, 9.63000E-01,
$ 1.14900E+00, 1.28000E+00, 1.38200E+00, 1.46000E+00, 1.58200E+00,
$ 1.66000E+00, 1.71200E+00, 1.75600E+00, 1.79900E+00, 1.82300E+00,
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```
     $ 3.16000E-01, 3.22600E-01, 3.43500E-01, 3.72400E-01, 4.00400E-01,
     $ 4.56700E-01, 5.09500E-01, 6.17100E-01, 7.31000E-01, 9.42500E-01,
     $ 1.12300E+00, 1.25800E+00, 1.35000E+00, 1.44000E+00, 1.56600E+00,
     $ 1.64600E+00, 1.73200E+00, 1.74900E+00, 1.79000E+00, 1.81900E+00,
     $ 2.43000E-01, 2.49000E-01, 2.70000E-01, 2.96000E-01, 3.29000E-01,
     $ 3.96700E-01, 4.62500E-01, 5.84800E-01, 7.03700E-01, 9.08200E-01,
     $ 1.08600E+00, 1.19100E+00, 1.32600E+00, 1.41000E+00, 1.54200E+00/
      DATA (BB2(J),J=96,190) /
     1 1.64000E+00, 1.68600E+00, 1.73700E+00, 1.78000E+00, 1.81000E+00,
     2 1.96200E-01, 2.00000E-01, 2.17700E-01, 2.36000E-01, 2.67200E-01,
     3 3.26500E-01, 3.95700E-01, 5.26300E-01, 6.35000E-01, 8.60000E-01,
     4 1.03800E+00, 1.18000E+00, 1.29200E+00, 1.38100E+00, 1.52800E+00,
     5 1.61000E+00, 1.67200E+00, 1.72200E+00, 1.77000E+00, 1.79500E+00,
     6 1.64400E-01, 1.71000E-01, 1.80600E-01, 2.03000E-01, 2.20100E-01,
     7 2.73700E-01  3.34400E-01, 4.67500E-01, 5.72200E-01, 8.00000E-01,
     8 9.81100E-01, 1.12700E+00, 1.24100E+00, 1.34100E+00, 1.48600E+00,
     9 1.57900E+00, 1.64900E+00, 1.71600E+00, 1.75300E+00, 1.78400E+00,
     $ 1.24000E-01, 1.23000E-01, 1.34000E-01, 1.46100E-01, 1.59900E-01,
     $ 1.96700E-01, 2.42900E-01, 3.44600E-01, 4.55000E-01, 6.67400E-01,
     $ 8.52700E-01, 1.00600E+00, 1.13300E+00, 1.24600E+00, 1.40900E+00,
     $ 1.52000E+00, 1.60000E+00, 1.66300E+00, 1.72100E+00, 1.76000E+00,
     $ 9.95000E-02, 1.00000E-01, 1.06500E-01, 1.15000E-01, 1.23700E-01,
     $ 1.48500E-01, 1.82000E-01, 2.62000E-01, 3.53600E-01, 5.45700E-01,
     $ 7.26900E-01, 8.84100E-01, 1.02200E+00, 1.14000E+00, 1.32100E+00,
     $ 1.45100E+00, 1.54700E+00, 1.62100E+00, 1.69000E+00, 1.73500E+00,
     $ 8.30000E-02, 8.50000E-02, 8.90000E-02, 9.10000E-02, 1.00000E-01,
     $ 1.17000E-01, 1.43000E-01, 2.05000E-01, 2.78000E-01, 4.41000E-01/
      DATA (BB2(J),J=191,285)/
     1 6.10000E-01, 7.58000E-01, 9.08000E-01, 1.02800E+00, 1.22800E+00,
     2 1.37000E+00, 1.47800E+00, 1.56200E+00, 1.64900E+00, 1.70100E+00,
     3 7.12000E-02, 7.20000E-02, 7.56000E-02, 8.00000E-02, 8.46000E-02,
     4 9.82000E-02, 1.15600E-01, 1.64700E-01, 2.24900E-01, 3.66400E-01,
     5 5.17300E-01, 6.65400E-01, 8.00000E-01, 9.24400E-01, 1.13100E+00,
     6 1.28800E+00, 1.40100E+00, 1.50300E+00, 1.60000E+00, 1.66300E+00,
     7 6.24000E-02, 6.30000E-02, 6.50000E-02, 6.90000E-02, 7.20000E-02,
     8 8.40000E-02, 9.80000E-02, 1.38000E-01, 1.85000E-01, 3.07700E-01,
     9 4.39000E-01, 5.71000E-01, 7.06000E-01, 8.30000E-01, 1.04200E+00,
     $ 1.20300E+00, 1.32900E+00, 1.43200E+00, 1.54300E+00, 1.61700E+00,
     $ 5.55000E-02, 5.60000E-02, 5.67600E-02, 6.00000E-02, 6.43000E-02,
     $ 7.20000E-02, 8.38000E-02, 1.15300E-01, 1.55600E-01, 2.60000E-01,
     $ 3.74500E-01, 4.98000E-01, 6.20000E-01, 7.38300E-01, 9.46700E-01,
     $ 1.12000E+00, 1.25200E+00, 1.37000E+00, 1.48100E+00, 1.56700E+00,
     $ 4.98000E-02, 5.00000E-02, 5.05000E-02, 5.20000E-02, 5.65000E-02,
     $ 6.90000E-02, 7.25000E-02, 9.90000E-02, 1.31000E-01, 2.19000E-01,
     $ 3.21000E-01, 4.32000E-01, 5.50000E-01, 6.56000E-01, 8.61000E-01,
     $ 1.04000E+00, 1.18100E+00, 1.30000E+00, 1.43700E+00, 1.51600E+00,
     $ 4.54000E-02, 4.54000E-02, 4.54000E-02, 4.90000E-02, 5.08000E-02/
      DATA (BB2(J),J=286,380)/
     1 5.65000E-02, 6.46000E-02, 8.62000E-02, 1.14800E-01, 1.89500E-01,
     2 2.79900E-01, 3.83200E-01, 4.88000E-01, 5.89800E-01, 7.87400E-01,
     3 9.61400E-01, 1.11800E+00, 1.23400E+00, 1.35900E+00, 1.46300E+00,
     4 3.84000E-02, 3.90000E-02, 4.00000E-02, 4.10000E-02, 4.30000E-02,
     5 4.60000E-02, 5.60000E-02, 6.70000E-02, 8.90000E-02, 1.42000E-01,
     6 2.18000E-01, 2.99000E-01, 3.88000E-01, 4.82000E-01, 6.52000E-01,
     7 8.26000E-01, 9.83000E-01, 1.10900E+00, 1.23800E+00, 1.35200E+00,
```

```
8 3.33000E-02, 3.30000E-02, 3.30000E-02, 3.40000E-02, 3.57000E-02,
9 3.93000E-02, 4.37000E-02, 5.56000E-02, 7.17000E-02, 1.15200E-01,
$ 1.71400E-01, 2.37200E-01, 3.18000E-01, 3.88100E-01, 5.46900E-01,
$ 7.04200E-01, 8.52000E-01, 9.81500E-01, 1.12300E+00, 1.24100E+00,
$ 2.86000E-02, 2.80000E-02, 2.80000E-02, 2.80000E-02, 2.90000E-02,
$ 3.30000E-02, 3.60000E-02, 4.10000E-02, 5.80000E-02, 9.00000E-02,
$ 1.32000E-01, 1.90000E-01, 2.52000E-01, 3.18000E-01, 4.57000E-01,
$ 6.03000E-01, 7.43000E-01, 8.48000E-01, 9.96000E-01, 1.11800E+00,
$ 2.50000E-02, 2.50000E-02, 2.50000E-02, 2.50000E-02, 2.61000E-02,
$ 2.82000E-02, 3.08000E-02, 3.76000E-02, 4.70000E-02, 7.24000E-02,
S 1.06400E-01, 1.47700E-01, 1.92000E-01, 2.47900E-01, 3.63000E-01,
$ 4.85500E-01, 6.09000E-01, 7.29300E-01, 8.70000E-01, 1.00100E+00/
 DATA (TBV1(J),J=1,8) /
10.,40000.,80000.,120000.,140000.,160000.,200000.,240000./
 DATA (TBV2(J),J=1,8) /
1.08,.11,.20,.45,.51,.49,.42,.32 /
 END



      SUBROUTINE ATMOS (Z,TM,SIGMA,RHO,THETA,DELTA,CA,AMU,K)
C     ****************************************************************
C     CALLING SEQUENCE
C
C     CALL ATMOS(Z,TM,SIGMA,RHO,THETA,DELTA,CA,AMU,K)
C
C     Z     = GEOMETRIC ALTITUDE (FT)
C     TM    = MOLECULAR SCALE TEMPERATURE (DEGREES RANKIN)
C     SIGMA = RATIO OF DENSITY TO THAT AT SEA LEVEL
C     RHO   = DENSITY LB-SEC**2-FT**(-4) OR SLUGS-FT**3
C     THETA = RATIO OF TEMPERATURE TO THAT AT SEA LEVEL
C     DELTA = RATIO OF PRESSURE TO THAT AT SEA LEVEL
C     CA    = SPEED OF SOUND (FT/SEC)
C     AMU   = VISCOSITY COEFFICIENT (LB-SEC-FT**2)
C
C     K = 1 NORMAL,
C       = 2 ALTITUDE GREATER THAN 300000. FT.,
C       = 3 ALTITUDE NEGATIVE,
C       = 4 FLOATING POINT OVERFLOW,
C       = 5 ALTITUDE GREATER THAN 300000. FT. AND FLOATING POINT OVERFL.
C
C     ATMOS IS CALLED BY ROUTINES BLAST1 AND THERM
C     ****************************************************************
      DIMENSION HPRIMB(11),TMB(11),SIGMAB(11),ALM(11)
      DATA(HPRIMB(I),I=1,11)/
     1          0.    ,     36089.239,     82020.997,     154199.480,
     2     173884.510,     259186.350,     295275.590,     344488.190,
     3     524934.380,     557742.780,     656167.980/
```

```
      DATA(TMB(I),I=1,11)/
     1      518.688,     389.988,     389.988,     508.788,
     2      508.788,     298.188,     298.188,     406.188 ,
     3     2386.188,    2566.188,    2836.188/
      DATA(SIGMAB(I),I=1,11)/
     1 1.0000000E 00,   2.9706958E-01,   3.2665751E-02, 1.2117870E-03,
     2 5.8677311E-04,  5.8677311E-04, 1.7928595E-06, 9.3921519E-08,
     3 7.7658593F-10,   5.6324877E-10,    2.5726771E-10/
      DATA(ALM(I),I=1,11)/
     1 -0.00356616,  0.          ,  0.00164592,  0.         ,
     2 -0.00246888,  0.          ,  0.00219456,  0.00197280,
     3  0.00548640,  0.00274320,  0.00192024/
      DATA  Q  /  0.118744176  /  ,  RE  /  2.0855531E 07  /,
     1       S  /  198.72       /  ,  PZ  /  2116.2        /,
     2   AMUZ  /  3.7372998E-07/  ,RHOZ  /  0.0023769      /,
     3    TMZ  /  518.688      /
      K=1
      IF (Z) 10,30,20
10    K=3
      GO TO 110
20    IF (Z.GT.300000.) K=K+1
30    HPRIM=(RE/(RE+Z))*Z
      DO 40 M=1,11
      IF (HPRIM-HPRIMB(M)) 50,60,40
40    CONTINUE
      M=12
50    M=M-1
60    IF (ALM(M)) 70,80,70
70    TM=TMB(M)+ALM(M)*(HPRIM-HPRIMB(M))
      SIGMA=EXP((1.0+(Q/ALM(M)))*(ALOG(TMB(M)/TM)))*SIGMAB(M)
      GO TO 90
80    TM=TMB(M)
      SIGMA=SIGMAB(M)*EXP(-(Q*(HPRIM-HPRIMB(M)))/TMB(M))
90    RHO=RHOZ*SIGMA
      THETA=TM/TMZ
      DELTA=SIGMA*THETA
      CA=49.02177*SQRT(TM)
      AMU=AMUZ*SQRT(THETA**3)*((TMZ+S)/(TM+S))
110   RETURN
      END
```

```
      SUBROUTINE MACURE (Z,XA1,XA2,XA3,XA4,XA5,XA6,IE,ZR)
C     ******************************************************************
C     SUBROUTINE MACURE EXECUTES AN N DIMENSIONAL TABLE LOOK UP
C     WITH EXTRAPOLATION IF DESIRED
C
C     CALLING SEQUENCE-
C
C     CALL MACURE(Z,XA1,XA2,XA3,XA4,XA5,XA6,IE,ZR)
C       WHERE
C                IE    =  ERROR CODE
C                         0  INTERPOLATION SUCCESSFUL
C                         -1 OR 1 ARGUMENT EXCEEDS LIMITS OF THE TABLE
C                         2  INDEPENDENT VARIABLES NOT IN ASCENDING ORDER
C                Z( 1)= F(X1,Y1,Z1)          Z(13)= F(X3,Y1,Z1)
C                Z( 2)= F(X1,Y1,Z2)          Z(14)= F(X3,Y1,Z2)
C                Z( 3)= F(X1,Y2,Z1)          Z(15)= F(X3,Y2,Z1)
C                Z( 4)= F(X1,Y2,Z2)          Z(16)= F(X3,Y2,Z2)
C                Z( 5)= F(X1,Y3,Z1)          Z(17)= F(X3,Y3,Z1)
C                Z( 6)= F(X1,Y3,Z2)          Z(18)= F(X3,Y3,Z2)
C                Z( 7)= F(X2,Y1,Z1)          Z(19)= F(X4,Y1,Z1)
C                Z( 8)= F(X2,Y1,Z2)          Z(20)= F(X4,Y1,Z2)
C                Z( 9)= F(X2,Y2,Z1)          Z(21)= F(X4,Y2,Z1)
C                Z(10)= F(X2,Y2,Z2)          Z(22)= F(X4,Y2,Z2)
C                Z(11)= F(X2,Y3,Z1)          Z(23)= F(X4,Y3,Z1)
C                Z(12)= F(X2,Y3,Z2)          Z(24)= F(X4,Y3,Z2)
C
C     ******************************************************************
      COMMON/TBLKUP/L1,LF,NA(6),X (100),NNEX
      DIMENSION Z(1),        XA(6), NS(5), WJ(32), RATIO(5), NGROUP(5),
     1ITOT(5)
      IE=0
      NEXTR=NNEX
      XA(1)=XA1
      XA(2)=XA2
      XA(3)=XA3
      XA(4)=XA4
      XA(5)=XA5
      XA(6)=XA6
      DO 100 I=1,LF
      L2=L1+NA(I)-2
      FOUND=0.
      DO 50 J=L1,L2
    5 IF (X(J).GT.X(J-1)) GO TO 10
      IE=2
      RETURN
10    IF (FOUND.NE.0.) GO TO 50
      IF (XA(I)-X(J-1)) 20,50,50
20    IF (J.GT.L1) GO TO 40
      IF (NEXTR.EQ.0) GO TO 30
      FOUND=1.
      NS(I)=L1-1
      GO TO 50
30    IE=-1
      RETURN
40    FOUND=1.
```

```
      NS(I)=J-2
50    CONTINUE
      IF (FOUND) 90,60,90
60    IF (XA(I)-X(L2)) 80,30,70
70    IF (NEXTR.NE.0) GO TO 80
      IE=1
      RETURN
80    NS(I)=L2-1
90    L1=L2+2
100   CONTINUE
C     IN NS(I) IS THE SUBSCRIPT IN THE ARRAY X SUCH THAT
C     X(NS(I)) IS LESS THAN THE ITH ARGUMENT
      DO 110 I=1,LF
      K=NS(I)
      RATIO(I)=(XA(I)-X(K))/(X(K+1)-X(K))
C     IN RATIO(1) IS THE RATIO OF X ARG, RATIO(2)=RATIO OF Y ETC.
110   CONTINUE
      NGROUP(1)=NS(1)
      NSUM=NA(1)
      DO 120 I=2,LF
      NGROUP(I)=NS(I)-NSUM
      NSUM=NSUM+NA(I)
120   CONTINUE
C     IN NGROUP(I) IS THE SUBSCRIPT OF THE ITH VARIABLE SUCH
C     THAT THE TABLE VALUE IS LESS THAN THE CORRESPONDING ARGUMENT
C     THIS IS IN TERMS OF THIS VARIABLE ONLY
C     FOR A FUNCTION OF DEGREE ND WE NEED2**(ND-1) VALUES
C     FROM THE Z ARRAY
      ITOT(LF)=1
      DO 130 I=2,LF
      J=LF-I+1
      ITOT(J)=ITOT(J+1)*NA(J+1)
130   CONTINUE
C     IN ITOT(J) IS THE NUMBER OF LOCATIONS IN THE Z ARRAY NEEDED TO CH
C     THE JTH SUBSCRIPT
      KF=2**LF
      MW=-2
      DO 170 I=1,KF,2
      IFIRST=1
      MW=MW+2
      DO 160 J=1,LF
      MM=2**(J-1)
      IF (AND(MM,MW).EQ.0.) GO TO 140
      IMON=NGROUP(J)+1
      GO TO 150
140   IMON=NGROUP(J)
150   IFIRST=IFIRST+(IMON-1)*ITOT(J)
160   CONTINUE
      ISEC=IFIRST+ITOT(1)
      WJ(I)=Z(IFIRST)
      WJ(I+1)=Z(ISEC)
170   CONTINUE
      DO 180 I=1,LF
      KF=KF/2
      DO 180 J=1,KF
```

```
180   WJ(J)=WJ(2*J-1)+(WJ(2*J)-WJ(2*J-1))*RATIO(I)
      ZR=WJ(1)
      RETURN
      END




      SUBROUTINE SETUP (X,NEXTR,ND,NA1,NA2,NA3,NA4,NA5,NA6)
C     ****************************************************************
C     SUBROUTINE SETUP SETS UP ARRAYS FOR TABLE LOOK UP
C
C     CALLING SEQUENCE-
C
C     CALL SETUP(X,NEXTR,ND,NA1,NA2,NA3,NA4,NA5,NA6)
C       WHERE
C               X     =  TABLE OF INDEPENDENT VARIABLES
C               NEXTR=   0  NO EXTRAPOLATION
C                     =  1  EXTRAPOLATION IS DESIRED
C               ND    =  NUMBER OF DIMENSIONS (WHEN Z=F(X,Y), ND=3)
C               NA1   =  NO. OF VALUES FOR FIRST  INDEPENDENT VARIABLE
C               NA2   =  NO. OF VALUES FOR SECOND INDEPENDENT VARIABLE
C               NA3   =  NO. OF VALUES FOR THIRD  INDEPENDENT VARIABLE
C               NA4   =  NO. OF VALUES FOR FOURTH INDEPENDENT VARIABLE
C               NA5   =  NO. OF VALUES FOR FIFTH  INDEPENDENT VARIABLE
C               NA6   =  NO. OF VALUES FOR SIXTH  INDEPENDENT VARIABLE
C
C     ****************************************************************
      COMMON/TBLKUP/L1,LF,NA(6),XL(100),NNEX
      DIMENSION X(1),     XA(6), NS(5), WJ(32), RATIO(5), NGROUP(5),
     1ITOT(5)
      DO 10 I=1,NA1
10    XL(I)=X(I)
      K=NA1+1
      L=NA1+NA2
      DO 12 I=K,L
   12 XL(I)=X(I)
      NNEX=NEXTR
      NA(1)=NA1
      NA(2)=NA2
      NA(3)=NA3
      NA(4)=NA4
      NA(5)=NA5
      NA(6)=NA6
      L1=2
      LF=ND-1
      RETURN
      END
```

Appendix E

A Sample Problem

Input Data

Visibility at sea level	10 mi.
Water vapor pressure at sea level	8 mmHg
Albedo	.20
Haze layer above sea level	10,000 ft.

Vehicles		x,y,z Position (ft)		x,y,z Velocity Components (ft/sec)
1	x	3000	V_x	6000
	y	0	V_x	100
	z	2000	V_z	0
2		2000		600
		100		0
		1500		0
3		1000		400
		100		0
		1500		-500
4		1000		800
		0		0
		20000		0
5		1500		1000
		1000		0
		8000		0

Vulnerabilities

Thermal	10 cal/cm^2
Overpressure	8 psi
Dynamic pressure	5 psi

Height of ground above sea level 1000 ft

Bursts		x,y,z Position (ft)	Yield kT	Time (sec)
1	x	11,000	600	0.0
	y	0		
	z	35,000		
2		Targeted (spe = 800 ft)	10	15.0

Output Listing

-------VEHICLE INITIAL CONDITIONS------

VEHICLE	POSITION(X,Y,Z)(FT)			VELOCITY(X,Y,Z)		(FT/SEC)
1	3000.00	-0.00	2000.00	600.00	100.00	-0.00
2	2000.00	100.00	1500.00	600.00	-0.00	-0.00
3	1000.00	100.00	1500.00	400.00	-0.00	-500.00
4	1000.00	-0.00	20000.00	800.00	-0.00	-0.00
5	1500.00	1000.00	8000.00	1000.00	-0.00	-0.00

INPUT PARAMETERS--
NUMBER OF BURSTS ENTERED IS 2
VISIBILITY AT SEA LEVEL(MI.) IS 10.00
ALBEDO (GROUND REFLECTANCE) IS .20
H2O VAPOR PRESSURE(SEA LEVEL,MMHG) 8.00
STANDARD ATMOSPHERE SPECIFIED

------VEHICLE POSITIONS AT TIME OF BURST NUMBER 1------

VEHICLE	POSITION(X,Y,Z)(FT)			VELOCITY(X,Y,Z)		(FT/SEC)
1	3000.00	0.00	2000.00	600.00	100.00	-0.00
2	2000.00	100.00	1500.00	600.00	-0.00	-0.00
3	1000.00	100.00	1500.00	400.00	-0.00	-500.00
4	1000.00	0.00	20000.00	800.00	-0.00	-0.00
5	1500.00	1000.00	8000.00	1000.00	-0.00	-0.00

-----WEAPON BURST POSITIONED BY USER-----
NUCLEAR DETONATION COORDINATES ARE 11000.0, -0.0, 35000.0
GROUND HEIGHT ABOVE SEA LEVEL= 1000.0 FT
INCREMENTAL TIME OF BURST= -0.0 SEC

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LOSSES FROM BURST NUMBER 1 (600.0KT)

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RESULTS FROM THERMAL EFFECTS COMPUTATIONS

THERMAL EFFECTS PARAMETERS FOR VEHICLE NUMBER 1

UNATTENUATED FLUENCE (CAL/CM2)	12.5574
HEIGHT OF BURST (FT)	35000.0000
SLANT RANGE AT TIME OF PEAK RADIANT POWER (MI.)	6.4193
TIME TO PEAK RADIANT POWER (SEC)	.4444
DIRECT FREE FIELD FLUENCE (CAL/CM2)	8.0913
DIRECT NORMALLY INCIDENT FLUENCE(CAL/CM2) (NORMAL TO A PLANE HORIZONTAL RECEIVER)	7.8778

THERMAL EFFECTS PARAMETERS FOR VEHICLE NUMBER 2

UNATTENUATED FLUENCE (CAL/CM2)	12.0364
HEIGHT OF BURST (FT)	35000.0000
SLANT RANGE AT TIME OF PEAK RADIANT POWER (MI.)	6.5568
TIME TO PEAK RADIANT POWER (SEC)	.4444
DIRECT FREE FIELD FLUENCE (CAL/CM2)	7.5485
DIRECT NORMALLY INCIDENT FLUENCE(CAL/CM2) (NORMAL TO A PLANE HORIZONTAL RECEIVER)	7.3044

THERMAL EFFECTS PARAMETERS FOR VEHICLE NUMBER 3

UNATTENUATED FLUENCE (CAL/CM2)	11.6936
HEIGHT OF BURST (FT)	35000.0000
SLANT RANGE AT TIME OF PEAK RADIANT POWER (MI.)	6.6522
TIME TO PEAK RADIANT POWER (SEC)	.4444
DIRECT FREE FIELD FLUENCE (CAL/CM2)	7.2296

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     DIRECT NORMALLY INCIDENT FLUENCE(CAL/CM2)                 6.9411
     (NORMAL TO A PLANE HORIZONTAL RECEIVER)

     ----VEHICLE NUMBER  4 HAS BEEN SUBJECTED TO THERMAL FLUENCE OF
           43.7844(CAL/CM2) AND HAS BEEN REMOVED FROM THE PROGRAM
     ----THE THERMAL VULNERABILITY LEVEL IS    10.0000 (CAL/CM2)


 THERMAL EFFECTS PARAMETERS FOR VEHICLE NUMBER  4


     UNATTENUATED FLUENCE (CAL/CM2)                           45.3626

     HEIGHT OF BURST (FT)                                  35000.0000

     SLANT RANGE AT TIME OF PEAK RADIANT POWER (MI.)           3.3775

     TIME TO PEAK RADIANT POWER (SEC)                           .4444

     DIRECT FREE FIELD FLUENCE (CAL/CM2)                      43.7844

     DIRECT NORMALLY INCIDENT FLUENCE(CAL/CM2)                36.8287
     (NORMAL TO A PLANE HORIZONTAL RECEIVER)

     ----VEHICLE NUMBER  5 HAS BEEN SUBJECTED TO THERMAL FLUENCE OF
           15.1413(CAL/CM2) AND HAS BEEN REMOVED FROM THE PROGRAM
     ----THE THERMAL VULNERABILITY LEVEL IS    10.0000 (CAL/CM2)


 THERMAL EFFECTS PARAMETERS FOR VEHICLE NUMBER  5


     UNATTENUATED FLUENCE (CAL/CM2)                           17.7687

     HEIGHT OF BURST (FT)                                  35000.0000

     SLANT RANGE AT TIME OF PEAK RADIANT POWER (MI.)           5.3969

     TIME TO PEAK RADIANT POWER (SEC)                           .4444

     DIRECT FREE FIELD FLUENCE (CAL/CM2)                      15.1413

     DIRECT NORMALLY INCIDENT FLUENCE(CAL/CM2)                14.3466
     (NORMAL TO A PLANE HORIZONTAL RECEIVER)
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RESULTS FROM BLAST EFFECTS COMPUTATIONS

SHOCK FRONT PARAMETERS AT INTERCEPT OF VEHICLE NUMBER 1
VEHICLE POSITION AT SHOCK INTERCEPT(X,Y,Z) 21259. 3043.

RECEIVER HEIGHT AT SHOCK INTERCEPT (FT)	2000.0000
SLANT RANGE AT SHOCK INTERCEPT (FT)	34691.5573
TIME OF SHOCK ARRIVAL (SEC)	15.2308
SHOCK FRONT VELOCITY (FT/SEC)	1139.9103
PEAK DYNAMIC PRESSURE (PSI)	.0214
PEAK OVERPRESSURE (PSI)	.9085
PEAK MATERIAL VELOCITY (FT/SEC)	51.2153
PEAK OVERDENSITY (SLUGS/FT**3)	.0023
POSITIVE DURATION OF OVERDENSITY (SEC)	2.7949
POSITIVE DURATION OVERPRESSURE (SEC)	2.8494
POSITIVE DURATION MATERIAL VELOCITY (SEC)	3.4096

SHOCK FRONT PARAMETERS AT INTERCEPT OF VEHICLE NUMBER 2
VEHICLE POSITION AT SHOCK INTERCEPT(X,Y,Z) 20268. 100.

RECEIVER HEIGHT AT SHOCK INTERCEPT (FT)	1500.0000
SLANT RANGE AT SHOCK INTERCEPT (FT)	34758.4690
TIME OF SHOCK ARRIVAL (SEC)	15.1488
SHOCK FRONT VELOCITY (FT/SEC)	1141.5747
PEAK DYNAMIC PRESSURE (PSI)	.0213
PEAK OVERPRESSURE (PSI)	.9156
PEAK MATERIAL VELOCITY (FT/SEC)	50.7852
PEAK OVERDENSITY (SLUGS/FT**3)	.0024

POSITIVE DURATION OF OVERDENSITY (SEC) 2.7743

POSITIVE DURATION OVERPRESSURE (SEC) 2.8290

POSITIVE DURATION MATERIAL VELOCITY (SEC) 3.3841

----VEHICLE NUMBER 3 HAS INTERCEPTED
GROUND LEVEL AND HAS BEEN REMOVED.

------VEHICLE POSITIONS AT TIME OF BURST NUMBER 2------

VEHICLE	POSITION(X,Y,Z) (FT)			VELOCITY(X,Y,Z) (FT/SEC)		
1	12080.00	1500.00	2000.00	600.00	100.00	-0.00
2	11080.00	100.00	1500.00	600.00	-0.00	-0.00

-----WEAPON BURST POSITIONED BY SUBROUTINE TARGET-----
THE TARGET VEHICLE IS VEHICLE # 1
GROUND HEIGHT ABOVE SEA LEVEL= 100.0 FT
INCREMENTAL TIME OF BURST= 15.0 SEC
BURST DETONATION AT 589.179FT FROM TARGET VEHICLE
NUCLEAR DETONATION COORDINATES ARE 12555.8 1504.6 2195.3

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LOSSES FROM BURST NUMBER 2 (10.0KT)

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RESULTS FROM THERMAL EFFECTS COMPUTATIONS

----VEHICLE NUMBER 1 HAS BEEN SUBJECTED TO THERMAL FLUENCE OF
1147.9366(CAL/CM2) AND HAS BEEN REMOVED FROM THE PROGRAM
----THE THERMAL VULNERABILITY LEVEL IS 10.0000 (CAL/CM2)

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THERMAL EFFECTS PARAMETERS FOR VEHICLE NUMBER  1


     UNATTENUATED FLUENCE (CAL/CM2)                          12[illegible]2.9983

     HEIGHT OF BURST (FT)                                    2195.3262

     SLANT RANGE AT TIME OF PEAK RADIANT POWER (MI.)           .0981

     TIME TO PEAK RADIANT POWER (SEC)                          .1266

     DIRECT FREE FIELD FLUENCE (CAL/CM2)                     1147.9365

     DIRECT NORMALLY INCIDENT FLUENCE(CAL/CM2)                432.7175
     (NORMAL TO A PLANE HORIZONTAL RECEIVER)

     REFLECTED FLUENCE (CAL/CM**2)                             .0733

     REFLECTED + DIRECT NORMAL FLUENCE (CAL/CM2)              0.0000
     (COMPUTED ONLY IF BURST BELOW RECEIVER)

     ----VEHICLE NUMBER  2 HAS BEEN SUBJECTED TO THERMAL FLUENCE OF
            59.8484(CAL/CM2) AND HAS BEEN REMOVED FROM THE PROGRAM
     ----THE THERMAL VULNERABILITY LEVEL IS   10.0000 (CAL/CM2)

THERMAL EFFECTS PARAMETERS FOR VEHICLE NUMBER  2


     UNATTENUATED FLUENCE (CAL/CM2)                            69.5182

     HEIGHT OF BURST (FT)                                    2195.3262

     SLANT RANGE AT TIME OF PEAK RADIANT POWER (MI.)           .4082

     TIME TO PEAK RADIANT POWER (SEC)                          .1266

     DIRECT FREE FIELD FLUENCE (CAL/CM2)                       59.8484

     DIRECT NORMALLY INCIDENT FLUENCE(CAL/CM2)                 19.3956
     (NORMAL TO A PLANE HORIZONTAL RECEIVER)

     REFLECTED FLUENCE (CAL/CM**2)                             .0664

     REFLECTED + DIRECT NORMAL FLUENCE (CAL/CM2)              0.0000
     (COMPUTED ONLY IF BURST BELOW RECEIVER)


RESULTS FROM BLAST EFFECTS COMPUTATIONS
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Vita

Robert Gene DeRaad was born on 21 December 1944, in Ireton, Iowa. He was graduated from high school at Brandon, South Dakota, in 1962 and received the degree of Bachelor of Science in Mechanical Engineering from South Dakota State University in June 1966. He worked as a project engineer for The Army Materiel Command, Rock Island Arsenal until entering the USAF in February 1968. He received a commission in the USAF Reserve upon graduating from Officer Training School, Lackland AFB, Texas, in May 1968. Assigned to Logistics Command, he served as a project engineer for egress systems in the Service Engineering Division of the San Antonio Air Materiel Area. In August 1970 he was assigned to The Air Force Institute of Technology and in May 1971 he received a commission in the Regular Air Force. He is a member of PI TAU SIGMA, honorary society for Mechanical Engineers, and the American Nuclear Society.

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This thesis was typed by Jane Manemann.